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WATER SOFTENING & PURIFICATION

WATER SOFTENING

AND

PURIFICATION

THE SOFTENING AND CLARIFICATION OF HARD AND DIRTY WATERS

BY

HAROLD COLLET

(STANHOPE WATER ENGINEERING CO., LIMITED, LONDON)

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WATER PURIFICATION.

CHAPTER I.

WATER SUPPLIES.

Pure water is sought for in the arts and manufactures, that is to say, water not only clear and free from matter in suspension, but also as devoid as possible of dissolved impurities. In both respects distilled water would be the ideal water for manufacturers. And in fact, where, by the condensation of steam after use, distilled water is produced, it is frequently collected for employment in the works. Especially is this the case where the buildings are artificially heated by steam, but in almost every case there must be a considerable loss by leakage, so that the condensed steam, if in itself suitable, is not sufficient in quantity to supply the boilers.

Rain water stands next in purity, but the area from which it can be conveniently collected is so restricted in all cases that its extensive use is not possible. It can generally only be collected from the factory roofs, and as these are always covered with soot, dust and similar impurities, the rain water becomes contaminated, and sometimes even slightly acid. Rain

water from roofs in manufacturing towns is, during at least the first portion of a long continued downfall, very hard, sometimes as hard as 25 or 30 degrees, but after a time this sinks to about 3 degrees. The meaning of degrees of hardness is explained later on.

Rain water and distilled water being unavailable, manufacturers have to depend either upon the town supply or upon the water which they can draw from springs, wells or streams. Such waters are generally what is called hard.

Hard water contains in solution the bicarbonates, sulphates, chlorides or nitrates of lime and magnesia. The bicarbonate of iron, alumina and silica are also generally present in natural waters, but seldom in such proportion as to be of practical importance, rarely, in fact, amounting together to more than one grain per gallon.

Hardness is frequently described as being of two kinds, temporary and permanent. The temporary hardness is that due to the bicarbonates of lime and magnesia, and is so called because *prolonged* boiling will, by driving off part of the combined carbonic acid, cause the precipitation of the greater portion of the above impurities, leaving the water proportionately softer. The permanent hardness is due to the sulphates, chlorides and nitrates of lime and magnesia, and is not diminished by boiling at atmospheric pressure. But this distinction between temporary and permanent hardness fails altogether as soon as the water enters a boiler, for at the very high tem-

perature of a boiler under high steam pressure, the sulphate of lime becomes insoluble, and the chloride of magnesium, inert while cold, becomes actively corrosive.

Temporary hardness can be removed by means of lime, generally but not always to the same extent as by boiling, and much more cheaply. Boiling costs not less than 1*s.* per thousand gallons, while lime will soften the same quantity for a farthing.

The impurities of water are of course not limited to the substances in solution. Very often water holds in suspension mineral and organic matters which give much trouble and are difficult to get rid of. But such visible impurities are less injurious than those in solution, and consequently invisible and apt to be overlooked. It is a mistake to judge a water by its appearance alone. It must not be concluded that a water is suitable for use simply because it is clear and perfectly colourless. Clear bright water is frequently obtained at considerable expense, which gives all sorts of trouble in use, while a dirty-looking stream close by might have yielded a water better suited to the purposes of the user.

Many manufacturers use the water supplied by the water companies, in spite of high prices, their belief generally being that it must be the best procurable. And for drinking it almost always is the best, for when the sources of town supplies are chosen, the chief object kept in view is that it shall be drinkable and free from

organic taint. But for manufacturers it is frequently much inferior in usefulness to the surface streams and wells at their command; while the difference in cost is generally so great that even if the local stream or well be originally much inferior in quality to the town supply, the cost of pumping, softening and purifying it will amount to only a fraction of the price of town's water. Yet it is quite common to see even large works supplied with costly water, while a serviceable stream runs past the very walls.

Yet hard water is always really dear. If there are two supplies, one very soft costing 1*s.* per thousand gallons, the other very hard costing ½*d.* per thousand gallons, the first is really the cheaper in use. But if the hard water can be softened, the positions are at once reversed.

The price of town water to manufacturers varies from 4*d.* to 1*s.* 6*d.* per thousand gallons, and it is almost always the case that the 4*d.* water is very soft, while the 1*s.* 6*d.* water is very hard. The soft water is almost invariably surface water, collected from the hills or downs and received into natural lakes or artificial reservoirs. Such water, if it comes from moorlands, is frequently peaty and occasionally even slightly acid, but it is never hard, as it has never penetrated into the ground and so dissolved any of the lime or magnesia salts lying below the surface. Such carbonate hardness as it does contain is generally due to small springs which mix their waters with the surface flow. Among

the towns with surface or gravitation water supplies may be named Manchester, Liverpool, Edinburgh, Glasgow, Bradford, Leeds, Oldham, Preston, Barnsley, Belfast, and most of the large towns in Scotland, Yorkshire and Lancashire.

The price of these soft waters in large quantities averages 4*d.* per thousand gallons, and their hardness averages 4 degrees. This is simply a coincidence, but is a curious one, and becomes more noticeable still when compared with harder supplies.

The hard water supplies are drawn from rivers, wells or springs, and the water has in most cases first penetrated the layers of mineral deposits, and has dissolved away part of them. Water varies in hardness and in the nature of its hardness according to the strata from which it is drawn. The hardest well waters come from a combination of gypsum and magnesian limestone; such wells are very frequent round Birmingham and Bradford, but are not used for the town supplies. Brine wells are of course harder still, but scarcely come under the head of natural waters, and the same is the case with shallow wells near estuaries, as on the banks of the Thames; such wells contain a mixture of sea water and land water, and are seldom fit for use at all.

The springs and wells in the chalk give water which is almost invariably excellent dietetically, but consistently hard to the extent of about 20 grains of carbonate of lime to every gallon. This hardness is chiefly of the kind we have referred to as temporary, and can be

easily and cheaply removed by means of the lime process of softening, which is explained in another chapter.

The Kent Water System, which supplies the south-eastern portion of London, draws its water entirely from wells sunk in the chalk, and the water is of the nature just described. Croydon, Dover, Hull, Brighton, Bath and Eastbourne are all supplied with chalk water of undoubted wholesomeness but of considerable hardness.

London is chiefly supplied from rivers, the water being drawn sufficiently high up to be almost free from pollution. The chief sources of supply are the Thames and the Lea, supplemented by the New River and numerous wells. The variations in the hardness of the London waters are chiefly due to the wells, which are harder than the rivers.

The various London water undertakings have now been taken over by the Metropolitan Water Board, but the water supplied by the Board is of course identical with that formerly supplied by the companies, and can hardly be furnished at a lower cost. Any advantages must be looked for in the distant future.

River water is largely derived from springs, and is therefore harder than mere surface water, but softer than spring or well water. The cost of town water varies really with the nature of the source, but it seems to rise with the hardness. As mentioned before, gravitation water averages 4 degrees of hardness, and costs 4*d.* per thousand gallons. River waters average 13

degrees of hardness, and 9*d.* per thousand gallons. Well waters average 20 degrees of hardness, and 1*s.* per thousand gallons. In effect the price is one halfpenny higher for each additional degree of hardness. The cause is, of course, that the soft water is more easily and cheaply obtained than the hard water, which can only be reached by expensive borings, machinery and artificial reservoirs.

It is impossible not to be struck with the fact that, with the notable exception of London, the greatest manufacturing centres of Great Britain are those supplied with soft water. Their growth is no doubt chiefly due to the neighbourhood of cheap coal, but the influence of soft water is manifest in such cases as Bradford and Manchester, whose water is among the softest in England, and which are devoted to the woollen and cotton trades. If, for example, Bradford were only supplied with hard water, its wool-washing industry would receive an immediate and heavy blow which would materially affect the whole of the local trade.

The lowest price charged anywhere for town's water is far in excess of the cost of pumping, and where a large quantity of water is used, it will pay the users to sink a well and pump their own water. If there is a stream or spring close at hand the cost of well sinking may be avoided. The saving in large establishments often amounts to over 1000*l.* a year. But if the pumped water is hard, it must be softened before use so as to prevent waste of fuel, cost of continually

cleaning boilers, damage to boilers, waste of soap, and other inconveniences of hard water.

The list of town waters which we now give has been compiled partly from official analyses and reports furnished by the various town authorities and water companies, and partly from independent analyses and tests. Many towns have more than one source of supply, and as all waters are apt to vary from time to time, the figures must be regarded not as invariable but as a fair average.

The hardness is given in "degrees Clark," each degree being equivalent in effect to one grain of carbonate of lime in a gallon of water ($\frac{1}{70,000}$). To turn degrees "Clark" into degrees "Frankland," divide by ·7. Each degree then indicates one grain (or part) in 100,000 grains (or parts) of water. The figures represent the soap-destroying property which is called hardness. Chemists differ among themselves as to the true meaning of temporary and permanent hardness. A water containing 10 degrees of carbonate of lime is, by boiling, reduced only to 3 degrees. Some chemists call the whole 10 degrees temporary, others consider the 7 degrees boiled out as being temporary, and the remaining 3 degrees as permanent. The fact is that what is permanent or lasting under certain circumstances, is only temporary or evanescent under others, and the two terms must be regarded as colloquial only, not scientific or exact.

HARDNESS OF TOWN WATER SUPPLIES.

Town or District	Hardness	Town or District	Hardness
Aberavon	soft	Bo'ness	15·0
Aberdare	8·0	Boston	11·0
Aberdeen	1·5	Bradford	4·0
Abingdon	hard	Bradford-on-Avon ..	15·5
Accrington	soft	Braintree	hard
Aldershot	16·0	Brecon	7·0
Arbroath	12·5	Bridgend	21·0
Ashford (Kent)	24·5	Bridgwater	7·5
Aylesbury, softened ..	4·0	Brightlingsea	15·0
Banbury	25·0	Brighton	16·0
Barnet	14·5	Bristol	18·0
Barnsley	4·0	Broadstairs	18·0
Basingstoke	15·0	Burgess Hill	8·5
Bath	17·0	Burnley	3·0
Batley	3·0	Burton-on-Trent ..	hard
Bedford	28·0	Cambridge	17·5
Belfast	9·0	Canterbury, softened	5·0
Berwick-on-Tweed ..	15·5	Cardiff	4·0
Beverley	20·0	Carlisle	6·5
Bexhill	11·0	Carnarvon	0·5
Bilston	19·5	Caterham, softened ..	3·5
Bingley	5·5	Chatham	23·0
Birkenhead	9·0	Chelmsford	19·0
Birmingham	3·0	Cheltenham	10·5
Birstall	4·0	Chester	8·0
Blackburn	3·0	Chesterfield	5·5
Blackpool	2·0	Clacton	hard
Blandford	12·0	Clevedon	14·5
Bognor	hard	Cleveland	3·5

HARDNESS OF TOWN WATER SUPPLIES—*continued.*

Town or District	Hardness	Town or District	Hardness
Clitheroe	5·0	Exeter	3·5
Colchester	12·0	Falkirk	2·0
Colne Valley, softened	5·0	Farnborough, softened	3·5
Coventry	28·5	Faversham	21·0
Cowes	14·5	Filey	11·0
Crowborough	2·5	Frimley, softened ..	3·5
Croydon	17·0	Folkestone	18·0
Cuckfield	6·0	Frome	25·0
Darlington	6·0	Gainsborough	23·0
Deal	17·5	Gateshead	11·5
Derby	22·0	Glasgow	1·5
Devonport	1·5	Gloucester	14·0
Dewsbury	2·0	Glusburn	3·0
Doncaster	9·0	Godalming	14·0
Dorchester	16·5	Goole (new supply 10°)	38·0
Dorking	3·0	Gosport	14·5
Dover	18·5	Grantham	16·5
Dublin	1·3	Grimsby	14·5
Dumbarton	1·5	Guildford	15·0
Dumfries	6·0	Halifax	2·5
Dundee	4·0	Hamilton	2·5
Dunfermline	1·5	Harrogate	3·0
Dunoon	2·0	Hastings	1·5
Durham	17·5	Hawarden	2·5
Eastbourne	20·0	Henley, softened ..	8·0
East Kent Co.	23·0	Hereford	6·0
East Surrey Co., softn'd.	4·0	Hertford	14·5
Edgbaston	12·0	Horsforth	8·0
Edinburgh	4·0	Hoylake	15·0

HARDNESS OF TOWN WATER SUPPLIES—*continued.*

Town or District	Hardness	Town or District	Hardness
Hucknall Torhard ..	8·0	London—Rest, average	16·0
Huddersfield	various	Louth	12·0
Hull	17·0	Lowestoft	9·5
Ilkeston	15·0	Luton	22·0
Ilkley	3·0	Lymington	6·5
Inverness	2·0	Macclesfield	6·0
Ipswich	20·0	Maidenhead	19·0
Jersey	5·0	Maidstone	16·0
Keighley	2·5	Maldon	3·5
Kelso	16·0	Malvern	6·0
Kettering	13·0	Manchester	3·0
Kidderminster	10·0	Mansfield	7·0
Kilmarnock	5·0	Margate	19·0
King's Lynn	14·0	Maryport	1·5
Knutsford	18·0	Matlock	1·5
Lanark	1·5	Merthyr Tydfil	4·0
Lancaster	1·5	Middlesbrough	8·5
Leamington, average ..	20·0	Mid-Kent Co.	17·0
Leatherhead	18·5	Mid-Sussex Co.	8·0
Leeds	4·5	Montrose	3·5
Leek	4·0	Motherwell	6·0
Leicester	17·5	Nantwich	12·0
Lewes	9·5	Newcastle-on-Tyne ..	11·5
Leyland	24·5	Newmarket	16·0
Lichfield	15·0	Newport, I.W.	20·5
Lincoln	19·0	Newport, Mon.	12·0
Liverpool, various ..	2·0	Newquay	3·0
Llanelly	2·0	Northampton	7·0
London—Kent system	21·0	Norwich	16·5

HARDNESS OF TOWN WATER SUPPLIES—*continued.*

Town or District	Hardness	Town or District	Hardness
Nottingham	10·5	St. Helens, Lancs, softd.	10·0
Oldham	2·5	Saltburn-on-Sea	5·0
Ormskirk	6·0	Scarborough	15·0
Oswestry	3·5	Selby	12·0
Oxford	18·0	Sevenoaks	16·0
Paisley	4·0	Shepton Mallet	10·0
Penistone	13·5	Skegness	3·0
Peterborough	22·0	Sleaford	22·5
Perth	3·0	Southampton, softened	6·0
Plymouth	1·5	Southborough	6·0
Pontypool	8·5	South Hants Co., softd.	8·0
Portland	13·5	South Essex Co. ..	29·0
Portsmouth	13·5	South Staffs. Co. ..	9·0
Preston	3·5	Stafford	9·5
Purley, softened	3·5	Staffs. Potteries Co. ..	14·0
Ramsgate	18·5	Stamford	16·5
Reading	15·0	Stirling	3·5
Redhill, softened	3·5	Stockport, softened ..	6·0
Retford	11·0	Stockton-on-Tees ..	8·5
Rickmansworth	18·0	Stonehaven	3·0
Ripon	6·0	Stourbridge, various ..	26·0
Rochdale	3·5	Strood	16·5
Rochester	23·0	Stroud	23·0
Romford	19·0	Sunderland	30·0
Rotherham	4·0	Sutton, softened ..	9·0
Rugby	26·0	Swansea	3·0
Ryde	14·5	Swindon	19·0
Saffron Walden, S. ..	11·0	Tamworth	12·0
St. Andrews	12·0	Thirsk	4·0

HARDNESS OF TOWN WATER SUPPLIES—*continued.*

Town or District	Hardness	Town or District	Hardness
Todmorden	3·0	Wey Valley	9·0
Tonbridge	17·5	Whitby	9·0
Torquay	3·0	Whitehaven	1·0
Tunbridge Wells.. ..	3·0	Wicklow	7·0
Tynemouth	5·0	Widnes	6·0
Uppingham, softened ..	8·5	Wigan	8·0
Uxbridge	18·0	Winchester..	15·5
Ventnor	18·5	Windsor	18·0
Wallasey	12·6	Wirral..	13·5
Wakefield	2·5	Witham	18·0
Warminster	6·0	Wokingham	10·0
Warrington	12·0	Worcester	8·0
Watford	20·0	Wolverhampton.. ..	15·0
Wath-upon-Dearne ..	24·0	Workington	1·0
Wellingborough, softnd.	13·0	Worthing	17·0
Weston-super-Mare ..	30·0	Wrexham, average ..	7·5
West Surrey Co.	15·0	Yeovil	19·0
Weymouth	14·5	York	11·5

HARDNESS OF RIVERS.

(Rivers vary much and rapidly. The following are average figures.)

River	At	Carbonates	Sulphates, etc.	Total Hardness
Aire	Wakefield ..	6·0	4·5	10·5
Chelmer	Chelmsford ..	11·5	3·5	15·0
Clyde	..	6·0	2·0	8·0
Dee	Aberdeen ..	1·0	0·5	1·5
Don	Sheffield	..	9·5	9·5
Frome	Frome	11·0	1·0	12·0
Hebble	Halifax	3·5	5·5	9·0
Irwell	Manchester ..	5·5	8·0	13·5
„	Salford	10·0	11·0	21·0
Lea	Hackney	16·0	5·0	21·0
„	Bow	13·5	8·0	21·5
Mersey	Stockport ..	3·5	9·0	12·5
„	Warrington ..	9·5	6·5	16·0
Orwell	Ipswich	17·5	7·5	25·0
Ouse	Wolverton ..	16·0	1·5	17·5
Thames	Hampton ..	12·0	3·0	15·0
„ low tide ..	Wandsworth ..	13·0	4·0	17·0
„ high tide ..	„ ..	15·0	6·0	21·0
„ spring tide	„ ..	13·0	12·0	25·0
„ low tide ..	London Bridge	..	..	30·0
„ high tide ..	„	..	..	90·0
„ low tide ..	Woolwich ..	..	..	80·0
„ high tide ..	„ ..	..	..	220·0
Trent	Nottingham ..	9·0	4·0	13·0
Tyne	Newcastle ..	9·0	87·0	96·0
„	Gateshead ..	7·0	193·0	200·0
Wandle	Wandsworth ..	13·0	4·5	17·5
Yare	Norwich	17·0	6·0	23·0

In all the above cases where the hardness amounts to 25 degrees and over, the extra hardness is due to the presence of sea water.

CHAPTER II.

WATER FOR STEAM BOILERS.

There is one employment of water which is common to nearly every industry, namely, for the production of steam, either for heating or for the development of motive power. For such purposes enormous quantities of water are converted into steam. As a result of this conversion, the impurities in the water are concentrated or precipitated in the boilers in the form of mud or scale. It would not at the first glance appear that a few grains of solid matter would have much effect in a large boiler, but on careful examination the few grains turn out to be in reality a few hundredweights or even tons. Then trouble is imminent.

Condensing engines of the largest size and of very high steam economy require about 2 gallons of water in the shape of steam every hour for every horse-power indicated. This refers only to the water evaporated in the boilers; the quantity of water used for condensing is generally twenty times as great. Smaller or inferior (but yet high class) engines require from 3 to 5 gallons per horse-power per hour, while small and low class engines need from 6 up to 15 gallons. With these last

we need not concern ourselves. Either their want of economy is due to their extremely small size, or their owners are altogether ignorant or careless of such questions, and never find out anything about them unless by sheer accident.

Taking three gallons per hour as a fair average, an engine developing 100 horse-power will require 3000 gallons of water evaporated in its boiler in a day of ten working hours, and if the water contains 15 grains of lime salts to the gallon (the average in London and many other towns) the deposit or scale formed in a single day will be 6½ lb., or about 2 cwt. in a month, or over a ton in a year, of which the larger portion will remain in the boiler in the form of scale until removed by hand. This amounts to about 35 cubic feet of mud or soft scale every year, or half that bulk of hard scale.

If all this scale were deposited on the outside of the boiler it might prove very beneficial, as its power of preventing the passage of heat would render it a very fair substitute for ordinary lagging. But as the deposit takes place inside the boiler, and particularly upon the furnace flues, fire tubes and circulating tubes, its non-conducting power becomes the source of much trouble and loss, and prevents the water from picking up heat from the furnaces.

A good Lancashire boiler, worked without forcing, and provided with a good clean economiser, will evaporate, when clean and well stoked, about 9 lb. of

water for every pound of good steam coal burnt in the furnaces. This may be regarded as the standard to be aimed at for such a boiler, and if it should in actual continuous work show a lower duty, investigation should be made to show where the loss of heat or waste of fuel occurs. Slightly better results may be obtained, even with much inferior and cheaper coal, if mechanical stoking is adopted, or if tubular boilers are used, but 9 lb. of water to 1 lb. of coal may be regarded as very good. If there is no economiser or feed-water heater, the evaporation will seldom be more than 8 lbs., and generally less.

Taking the cost of steam coal at 13*s.* a ton, a fair average price, the cost of evaporating 1000 gallons of water in a good boiler is about 6*s.* 6*d.* (half a ton of coal). But as the non-conducting scale forms in the boiler, the proportion of heat transferred from the fires to the water gradually becomes less, and in order to keep up steam the temperature of the furnace must be increased. This really means that the quantity of coal burnt must be increased, at a corresponding increase of cost.

The thickness, and the comparative resistance to the transmission of heat, of the furnace plate and its coating of scale are shown graphically in Fig. 1. The resistance to the passage of heat offered by wrought iron being taken as 1, that of copper is 0·4, of slate 9·5, of brick 16, of chalk 17, and of sulphate of lime 48.

The waste of fuel occasioned by scale and blowing out must be remembered when considering the cost of a water supply, from whatever source. The cost of the water before it enters the boiler is a **mere nothing**

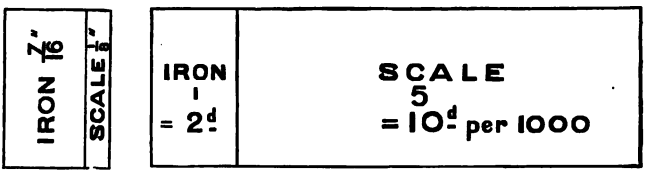

FIG. 1.

compared to the cost of evaporating it. Many waters would be dear at 1*d.* per thousand gallons, others are cheap at 1*s.* Hard water wastes in fuel, for every 1000 gallons, according to the thickness of scale in the boiler—

—	Per cent. Waste.			
	10	15	20	25
	Cost. *d.*	Cost. *d.*	Cost. *d.*	Cost. *d.*
With coal at 8*s.* per ton	4·8	7·2	9·6	12
„ 10*s.* „	6·0	9·0	12·0	15
„ 12*s.* „	7·2	10·8	14·3	18
„ 14*s.* „	8·4	12·6	16·8	21
„ 16*s.* „	9·6	14·4	19·2	24
„ 18*s.* „	10·8	16·2	21·6	27
„ 20*s.* „	12·0	18·0	24·0	30

To the above losses must be added the cost of frequently cleaning out the boilers, which is no small item. The cleaning of a simple under-fired cylindrical boiler is no easy task, and is seldom perfectly done, although every part can be easily got at. The difficulty is increased when internal flues and cross tubes are employed (which is almost always), and the plates are never fully cleaned from scale. A portion is removed where it is easy to do so, and the remainder is left to accumulate or crack off as chance may decree. The difficulty of cleaning is greater in multitubular boilers, so much so that the tubes would seldom be cleaned at all were it not for the imperative necessity to do so to save them from being burned through. Water-tube boilers are the most difficult of any to clean, if the scale is allowed to become at all hard, and in such cases the scale has to be literally drilled out with instruments like augers. It is in great measure owing to the difficulty of cleaning tubular boilers that the really less efficient Lancashire type is so all but universal. It may be taken approximately that boilers using hard water cost about 2*d.* per thousand gallons for proper cleaning, which is more than the cost of softening.

Steam users seldom take particular notice of their loss from scaled boilers, partly because it is not easy to gauge it, and partly because it remains pretty nearly the same from year to year; nevertheless it is very real and very heavy. Of course, if a boiler is larger than is required for its work, the loss of heat through scale

will be minimised. Instead of the hot gases parting with their heat quickly through clean plates, they will part with it more slowly through scaled plates, but the extra surface will allow it to be absorbed. But it must not be forgotten that a boiler which is larger than its requirements is thereby subject to special losses. For instance, it loses more heat through its outside or the brickwork setting than would a smaller boiler. Its firebars must also carry a thinner fire, and are therefore more likely to be frequently uncovered, when cold air will pass through. Nevertheless it is more economical to have even a large excess of capacity in a boiler than the very slightest deficiency, for a small boiler must always be forced, and a forced boiler must be kept clean, or it simply *eats* coal.

The waste of fuel is by no means the only trouble caused by scale. Many boiler explosions have been directly caused by it, and it ruins thousands of boilers annually. This is because, as the thickness of the scale increases between the water and the iron plate, the latter becomes less and less cooled by the water, and at length becomes soft and even red hot, and then it is, of course, unable to stand against the pressure of the steam, becomes bent out of shape and collapses. Or sometimes when the furnace plates are at high temperature the scale may crack or break away bodily from the iron, and the water thus allowed in contact with the red hot metal is instantaneously converted into steam, producing so sudden an increase of steam pressure as

to be in the nature of a shock which may cause an explosion.

Furnace plates wear away rapidly when coated with scale. This is attributed to "forcing the fires," but if the plates were kept clean it would seldom be necessary to force the fires, nor does a clean plate wear rapidly, even with a forced fire. The fact is that furnace plates of more than ½ inch thickness will gradually, and even rapidly, burn away until reduced to that thickness, even when kept clean inside, because thick plates are unable to conduct away the high temperature of the furnace gases. Thicker flue plates have often been tried, but with this result. Still more are they subject to be burned away if there is scale on the other side, for, as already shown, a little scale is as heat-resisting as a lot of iron. Fortunately the extremely rapid circulation of the water immediately over the firebars usually prevents the formation there of thick scale. On the other hand, the very high temperature usually causes a thin hard scale, like enamel, over the fire, even if there is but little deposit elsewhere, and that soft.

It is difficult to realise the economical difference between a clean boiler and a scaled one; but if any steam user will take the trouble to test them by putting them to exactly the same work for a fixed period, each in turn, carefully weighing the amounts of coal used and the quantity of water evaporated, he will be very much surprised at the difference. The loss will generally exceed 15 per cent.

Some waters are acid, either because they have dissolved organic acids from the peaty beds through which they have filtered or trickled, or because acids have been poured into them from factories, which is frequently the case with streams and canals. Many towns are supplied with gravitation or surface waters which have come from peaty moorlands, and these, although generally slightly alkaline from the presence of a small amount of carbonate of lime, are sometimes, and more especially in times of drought, distinctly acid. The organic acids present at such times are dangerous in two ways. Firstly, they corrode iron, and are therefore destructive to boilers. This may be overcome by putting *small* quantities of carbonate of soda (washing soda) into the boilers. Secondly, they are capable of dissolving lead in appreciable and even dangerous quantities, and as the water pipes inside houses are generally of lead, there is a possibility of lead poisoning. This very grave objection can be overcome by adding soda or causing the water to flow slowly over beds or lumps of chalk or limestone, when the carbonate of lime neutralises the acid, and renders the water very slightly alkaline, and therefore safe.

Acid waste liquors *should not be allowed* to run into streams or canals before being efficiently neutralised with chalk or lime. But what should be allowed, and what is allowed are very different things, and if boilers are fed from streams so acidified, the water must be effectually neutralised before entering the boilers,

otherwise the plates will rapidly corrode away. The easiest and only safe method of doing this is by the addition of carbonate of soda to the feed water in sufficient quantities. The water *in* the boilers should be tested for acidity every day, a little being taken at the gauge cocks for this purpose. An unfortunate circumstance is that acid waters are less likely to cause priming than any other, and owners and enginemen are therefore apt to regard them with favour on this account, ignorant of their corrosive powers.

Feed water from running streams generally contains a large amount of visible impurities, which remain in the boilers and mix with the precipitated deposit. Very finely divided vegetable matter is not always objectionable, and may even serve to keep the deposits from caking hard, and thereby facilitate blowing out. It is therefore frequently the case that filtered (not softened) river water may give more trouble in the boilers than it would if left unfiltered, and if the same water be softened, it is of little importance whether the vegetable matter is removed or not.

Earthy impurities, on the contrary, are invariably objectionable and even dangerous, and too much care cannot be taken to remove them, either by filtration or by softening. They generally contain a considerable proportion of clay, and on mixing with the ordinary boiler precipitates a hard scale is formed resembling Portland cement.

The mineral deposits in a boiler are not formed

merely by concentration of the dissolved salts, and, in fact, concentration has little to do with the question. We have, it is true, in one or two instances seen great masses of solid deposit taken from a boiler, of which by far the greater portion consisted of common salt crystallised, but this was due to the fact that the feed water was largely contaminated with sea water, that the boiler was rarely blown down, and that the boiler had no circulation. We found the lower part of such boiler cool to the hand even while under 50 lb. steam pressure. In such cases the boiler should be blown down at intervals during the day, and some cross tubes put into the horizontal flues to create a circulation.

All other precipitates result, not from concentration, but from high temperature. Lime salts which are quite soluble at 60° F. are quite insoluble at 300° F. Thus the carbonate (or bicarbonate) of lime is almost entirely precipitated at 212° F. under atmospheric pressure (that is to say, provided this temperature be maintained for some time), owing to carbonic acid gas being driven off. The same is the case with carbonate (or bicarbonate) of magnesia. Both of these substances are *totally* insoluble at 300° F. The sulphate of lime, which is largely soluble at low temperatures, is much less so at high ones. Few modern boilers are worked at lower temperature than 260° F., and consequently, as sulphate of lime in solution is pumped into a boiler under steam, precipitation at once commences. We say commences, for it takes half an hour or more for it

to be completed. Precipitated sulphate of lime is crystalline, heavy and compact, settles down quickly, making hard solid scale, and is difficult to remove, requiring the use of the chisel and chipping hammer. The carbonates of lime and magnesia, on the contrary, are light, and do not settle easily during working hours, owing to the circulation of the water, while the scale formed is comparatively soft, unless mixed with sulphate of lime or clay.

There is a great difference between the deposits made by precipitation at different points. When the precipitate is formed by heat or by chemical means, if the precipitate is actually *formed in contact* with anything solid, such as an iron plate or previous deposit, it will adhere to it, and become, as it were, one solid crystal. Tiny crystals of precipitate floating in the water do not cohere to each other, nor adhere to other substances that they may touch. They simply lie as powder or mud. But a quantity of loose crystals lying together may be cemented together solid by the precipitation of further crystals in their midst from the water with which they are mixed. Such further crystals are never, however, of carbonate of lime or magnesia, they are always the sulphate of lime, and the best way to ensure their absence is to see that no sulphate of lime is ever present in the feed water. Carbonate of soda, in sufficient quantity, is a certain preventive.

Scale is thinnest, as a rule, on the flue plates just over the fires, because the circulation and speed of the

water are at a maximum there, and the suspended matters are carried away to settle on reaching stiller parts of the boiler. The thickest scale is generally on the bottom of the boiler, where the water is coldest and stillest. There is frequently a very thick scale on the shell plates *above* the water level, caused by the rising bubbles of steam throwing up a spray of water containing precipitated chalk, which sticks to the plates and is baked hard by the heat.

The carbonates of lime and magnesia are only likely to form scale after precipitation if they lie upon a very hot surface and are not exposed to the circulation of the water. Such a case occurs if a boiler is emptied while hot; the mud that remains is baked hard and cannot afterwards be washed out. A boiler should be allowed to cool before being emptied, and if time is short this may be quickly and safely effected by running in cold water while the hot water is allowed to dribble out. By this method a boiler can be cooled down and then emptied in a few hours without risk of straining the plates, and where the boiler must be put into use again very quickly, this is the only proper method. If time permits it is still better, after cooling the water *very* slowly by the above means, to let the boiler stand full of cold water for one or two days before emptying. The carbonate deposits then remain as a white floury powder, which is easily swept or washed out; but as this latter is a rather messy operation, attendants are apt to blow off hot, which leaves

them less mud to wash out but more scale to remove when the inevitable chipping takes place.

Sulphate of lime forms a scale under all circumstances, varying in hardness and density according to the other impurities mixed with it, and the temperature to which it has been exposed. It has sometimes been stated that hard scale of sulphate of lime is not so dangerous and does not cause such waste as the softer carbonate or mixed scale. This is by no means everybody's experience. More burnt plates and tubes are found under hard scale than under soft, unless when oil is present in the soft scale. A great deal must depend upon the temperature of the furnaces. A forced fire of itself makes scale harder, and is also of course more likely to burn the plates than a moderate fire.

A soft muddy deposit is a great producer of priming; the steam rises through the water more irregularly and in larger bursts when it has to force its way through mud, and it always carries up with it a spray of chalk which naturally finds its way into the steam pipes and frequently into the engine cylinders. This tendency renders frequent blowing down and scumming imperative, and these are only very partial remedies at best.

The methods usually adopted for preventing and removing scale are:—

1. **Blowing down.** This is a necessity in every case, no matter what other means may be employed in

addition. Whenever water of more than 8 degrees of hardness is used, the blow-off cock should be opened for from two to five seconds *every hour*, and the scum cock as frequently and for as long a time, if the boiler has any scumming arrangement. Scumming is of most importance when the hardness of the water is due to carbonates or when boiler compositions are used, as in both cases the precipitate is very light and remains long in suspension, causing much priming or frothing. It is far better to blow off twelve times a day for a few seconds each time than once a day for a very much longer time; the effect in the boiler is in every case only local; the mud in and quite close to the cock is sucked off, and the circulation of the water then gradually brings more, which will be removed at the next opening, but after the first second or two all the mud which is at all within the influence of the blow-off cock has disappeared, and only plain water from above continues to pass out. This fact does not occur to the average boiler attendant, as he cannot see whether the water comes out muddy or clear, and he therefore saves himself trouble by blowing down only once a day, with bad results. If he saw what really occurs he would know better, but he can see nothing, and his imagination pictures a stream of mud flowing along the bottom of the boiler towards the mud cock. Nothing of this sort happens at all. The water *descends* from above, and the only part of the inside of the boiler influenced is in the shape of a cone with the point in the blow-off

cock and the wide end at the surface of the water. If a quantity of soft mud be thrown into a cistern full of water and allowed to settle, it will be seen that, upon opening a cock at the bottom, the mud just above the tap disappears through it, and then the mud just round it to an angle of 45 degrees, leaving a funnel through which clear water only continues to pass. The cistern may then be nearly emptied down to the level of the mud without any appreciable quantity of the latter escaping. This is exactly what occurs in a boiler. After the first second or two no more mud (or practically none) will pass out even if you blow down 3 feet; all you get rid of is good boiling water, and that means good money. *Blow down little and often.*

There are a few boilers still in use which are not fitted with blow-off cocks, but simply with plugs, which can only be removed when the boiler is to be emptied. Such an arrangement is mentioned only to be condemned. In such cases the workman who undertakes the risky job (supposing the boiler is still hot) has to knock the plug in, and then run for his life, and he may reckon himself lucky if he is not scalded. Even plugs which can be raised and lowered again are but little better, for when lowered it sometimes occurs that a piece of scale has got into or across the hole and prevents the plug from being forced home; the boiler then empties itself rapidly and the fires have to be drawn. This risk is quite sufficient to deter the attendant from blowing down more than once a week, which is to all

intents and purposes useless. A boiler which is only blown down once a week should be altogether emptied every week, and washed out. It is likely to be severely strained in so doing, and so every boiler ought to have at least one blow-off cock. Fortunately the boiler insurance companies have now rendered this almost universal.

Where several boilers have their blow-off cocks connected to a single sludge pipe or drain, it is of vital importance that the cock of any empty boiler shall be *closed* while any other boiler is being blown down. This is best ensured by using for all the cocks a single spanner, so fitted to them that it can only be put on or taken off any cock *when that cock is closed.* It has more than once happened that men at work inside one boiler have been scalded and suffocated by steam entering from another boiler through an open cock.

2. **Use of chemical agents or boiler compositions** in the boiler. These are so many and so various that it would be impossible here to refer to one-tenth of them. Most of them are valueless and even dangerous, although some are of use to keep a boiler under steam under conditions which would render it otherwise impossible. And the better the circulation of water in a boiler, the more effect a reagent will have in keeping it clean or comparatively clean. An under-fired boiler can scarcely be worked at all with hard water unless the deposit is artificially prevented from hardening. It will very soon burn out. Boilers with internal flues are ten

times safer, as the scale will not lodge or adhere on the convex top of a flue, as it must on the concave bottom of a boiler. But unless the flues are fitted with cross (or Galloway) tubes, the circulation will be confined almost entirely to that portion of the water which is above the level of the fire bars. The lower half will be dead water, and cold.

The safest, and therefore the best of all boiler compositions is the carbonate of soda, in any of its various forms as soda crystals, generally called washing or Scotch soda, concentrated crystal soda, sesquicarbonate of soda, crystal carbonate of soda, soda ash and pure alkali. These are all practically the same chemical, but in varying degrees of strength. The action of carbonate of soda is purely chemical, not mechanical, and its usefulness depends chiefly upon its power of decomposing the sulphate of lime and changing it into carbonate of lime. The sulphate forms a hard scale which is less easy to remove than the softer carbonate. Carbonate of soda also aids and quickens the precipitation of carbonate of lime and of carbonate of magnesia, and it has the curious effect of causing these carbonates to be precipitated in a smaller, finer, lighter condition than if heat alone is used, and the lighter precipitate has less tendency to agglomerate and harden. Carbonate of soda has another useful effect, that of neutralising any acid substances contained in the water which would otherwise pit or corrode the iron plates. These are the only services which can be rendered by carbonate of

soda. It does not prevent or diminish precipitation, but frequently increases it, for it throws down a precipitate from sulphate of magnesia which would otherwise remain in solution, neutral and harmless. Carbonate of soda is of little use unless in sufficient quantity to do all the chemical work required of it, while if used in excess of this, it causes foaming and priming, especially in tubular boilers. Some tubular boilers have a reputation for making wet steam; this is not a fault due to the boiler, but arises chiefly from the nature of the water and the presence of compositions which induce foaming; if fed with good water they will not prime, and the steam will be quite dry.

Caustic soda does not contain the carbonic acid needed to reduce sulphate of lime to carbonate of lime, and should only be used, if at all, when the water itself contains a fair quantity of carbonic acid, and it must then be put into the *cold* feed water; it at once turns into the carbonate of soda by absorbing carbonic acid. If a strong solution of caustic soda is pumped direct into the boiler, it will have no chance at all of doing proper work, but will be subject to all the disadvantages of carbonate of soda, and in a much greater degree.

Tannin and tannate of soda are frequently used. Their object, like that of soda, is to keep the deposit soft or in suspension, instead of forming hard scale. In this they are quite as successful as carbonate of soda, but are by no means safe. Tannin is decidedly

dangerous, and is to be unhesitatingly condemned, as the tannic acid which it contains, and upon which its efficiency depends, will attack not merely the lime salts but the iron plates themselves. It will in preference attack carbonate of lime, making a rather gelatinous and soft mixture, but it also attacks iron, although more slowly. A fair quality of ink may be made by dissolving iron in tannic acid; this will give some idea of its effect in a boiler. Tannate of soda is generally made by boiling spent tan bark in caustic soda, and the latter should be largely in excess. It is less effective than tannin, and of coürse less dangerous, but boilers in which it is used are sometimes badly corroded. Soluble preparations are made from eucalyptus, which are similar in their useful effect to the foregoing, but they would seem to be less dangerous. They are probably more carefully prepared. Their prices are high, altogether out of proportion to their cost and market value, but this is the case invariably with all boiler compositions.

Petroleum is sometimes put into boilers to prevent scale, this being a very common practice in America; of course only refined petroleum is used. Its action is purely mechanical. It does not cause a precipitate nor affect its size or shape, but gives an infinitesimal coating of oil to the crystals which prevents them from cohering. The effect is not lasting, as the petroleum or paraffin, which is rather a spirit than an oil, is gradually driven off with the steam. Crude petroleum contains heavier

matters of a tarry nature, which remain in the boiler, gather mud, and make a highly dangerous greasy deposit.

Hydrochloric acid has been tried. Its action is of course chemical and energetic, but dangerous in the extreme. There is scarcely one case in a hundred in which it could be safely used, even if added in measured quantities mathematically exact. This is never the case, for a reagent is always either in excess or in deficiency. When in excess it vigorously attacks the iron plates. Even when not in excess it turns magnesium carbonate into magnesium chloride, and the latter in its turn attacks the plates. The use of hydrochloric acid has been altogether abandoned, as has also (or nearly so) been that of ammonium chloride (sal-ammoniac), whose powers and drawbacks are similar in kind, although less in degree.

Many substances are put into boilers for the purpose of mixing mechanically with the lime deposit, and preventing it from becoming hard. Among them are Irish moss, seaweed, potatoes, tallow, oil, starch, linseed meal, sugar, molasses or treacle, stearine, gum, dextrine, mouldy bacon and other fats, spent tannin, dried leaves, logwood, sawdust and clay. Some of them are absolutely ridiculous, and all are dangerous.

Fluoride of Sodium has been tried in America. Its action is almost identical with that of carbonate of soda, but at ten times the cost. Insoluble fluorides of calcium and magnesium are formed, which are very fine

and do not easily settle. The effects of an excess we have not tried.

Without going so far as to say—"never use any boiler composition," we do say—"always find out *exactly* what your boiler composition consists of, and what are its effects and dangers." One of the attendant dangers is that, fearful of wasting or losing any of the costly composition, blowing-off is not only neglected but sometimes even avoided. The result is such an accumulation of soluble and insoluble matters in the boiler as to create the most serious risks.

Before leaving the subject of boiler compositions it should be remarked that, owing to the immense profit at which they are sold, a number of unscrupulous vendors of compositions "stand in" with equally unscrupulous boiler attendants, and the latter, in order to convince their employers that the stuff is effectually fetching off scale, adopt the trick of cracking off the scale when emptying the boiler, by methods at once risky and prejudicial to the boiler. These methods are alluded to further on.

3. **Internal apparatus for collecting precipitate** inside the boiler. The effect of these is very limited, and as their presence renders cleaning and scaling more difficult, they frequently do more harm than good. They are of two kinds. Through one the feed water passes when it first enters the boiler; the heat causes precipitation to begin in the collecting apparatus, and some of what remains there can be blown out at

intervals. But the collector itself scales up, while, unless it is inconveniently large and the pressure high, the precipitation is only partial, and only a portion of the precipitate can be blown out. The process of precipitation takes some considerable time, even at high temperatures.

The second kind of appliance is so connected by means of tubes that circulation of water takes place in it; a portion of the floating precipitate settles in it, and can be blown out at intervals. This apparatus does little more than is usually effected by the frequent use of the blow-off and scum cocks, and does not to any great degree prevent the accumulation of scale. When first fitted up it is usual to blow the collected mud into a tub, where it of course makes more show than if it had been blown through the blow-off cock straight to the drain; it is then assumed to be doing much useful work which would not otherwise have been done at all.

4. **Surface condensers,** the spent or exhaust steam being condensed and used again in the boiler, the waste or loss being made up with fresh water. This method is very good, where practicable, but has some drawbacks which are not at first very obvious.

Exhaust steam from an engine invariably carries away with it a little of the tallow or heavy oil with which the cylinders are lubricated. If such steam be passed through a surface condenser, the condensed water will retain the whole of this grease, and when pumped

back into the boiler it will be extremely likely to cause trouble. The reason is that the precipitates formed in the boiler from the hard make-up water stick to the oil, and float or are carried about by the currents until the greasy particles become by aggregation large enough and heavy enough to sink, and fall upon or are carried into contact with the flue plates or tubes. The greasy particles stick to whatever they touch, and gradually form a soft coating, which is by far the most dangerous form of incrustation known, as it is more non-conducting of heat than any other, and also absolutely prevents the water from reaching the iron. Other forms of scale are porous, but the oily deposit is quite impervious to moisture. The result is that if the furnace flame strikes upon a plate or tube coated with this greasy scale, the iron speedily becomes red-hot, bulges, and finally collapses.

This disastrous result can be avoided in several ways, more or less practical. Firstly, by using only distilled water to make up the loss caused by waste of steam or water. In this case there will be no precipitate at all in the boiler. The high cost of distilled water is prohibitive, but a good substitute may be found in rain water, provided there is sufficient catching area and rainfall to suit. The latter is not to be depended upon, however, and some substitute must be sought. In some districts water is obtainable which is nearly as soft as distilled water, as is the case with most rocky surface land, although sometimes peaty and

acid. In such a case it is advisable not merely to make up with this soft water, but also to almost entirely change the water in the boilers once a week by pumping in fresh water in large quantities, and running off the old greasy water *from the scum cocks.* The level of the water must never be allowed to fall to the top of the flues or tubes, as the greasy precipitate would stick to them, and the scum cocks are therefore to be preferred to the blow-off cocks, even when there is no fire in the furnaces.

The extreme danger of oily water will be well illustrated by the following experiment: Make a ball of iron or copper white hot, and dip it (suspended on a wire) into a bucket of clean water. It will quench quickly, with much hissing and evolution of steam. Make the ball again white hot, and dip it well under the surface in a bucket of water in which oil or soap is present in the form of an emulsion; there will be very little hissing, the metal will not quench, there will be little or no steam given off, and the ball is seen to be surrounded by a shell of vapour, like a soap bubble. The metal cools very gradually (mainly by radiation), the shell of vapour grows thinner and finally collapses with a report, volumes of steam being produced, while if the experiment be repeated in a glass vessel, the latter may be broken. The effect is that of a boiler explosion in miniature.

If naturally soft water is not obtainable for the make up, the water that is available should be softened

to as low a degree as possible before being used, so as to form the smallest possible quantity of precipitate in the boiler. Where a range of boilers are in use, it would be the best plan for one of them to be fed entirely with make-up water, and the others entirely with condenser water. The precipitate is thus confined entirely to the make-up boiler, and the oil to the others, so that there is no danger of greasy scale. Of course, with this arrangement it is necessary that the make-up water shall be softened, or else that there shall be a reserve boiler to work with the make-up water while the other is being cleaned out.

Or, instead of using chiefly condensed water in the boilers, with a small quantity of make-up water, the reverse practice may be employed where the engines are not of the condensing kind, the exhaust steam being turned into the hard water supply so as to heat it either previous to or during a process of softening. But it should be observed that the cold water must be *really hard*, for the grease is only removed mechanically by the precipitate formed during the softening process, which clings to and absorbs the grease and drags it down to the bottom of the clarifying vessel. It is evident that the harder the water the greater will be the quantity of precipitate, and the more complete the removal of the grease. The process is most effectually performed when the steam is not actually *blown into* the water, as in this case the oil, water and air form a milky emulsion which is more difficult to clarify; if

the steam is only blown *on to* the water, the oil floats on the top in a coherent film, and is more easily removed.

The advantages attaching to the use of distilled water in boilers have induced chemists to endeavour to remove the oil from condensed exhaust steam. These efforts have been successful, and most oily waters can be clarified efficiently at a very low cost. The practical methods are:—

1. By softening and filtering.
2. By precipitation of alumina and filtering.
3. By electrical treatment and filtering.
4. By filtration only.

The first three methods are radically similar, inasmuch as the oil is absorbed by the precipitate produced by the process, and such precipitate needs subsequent filtration. The three methods are described in another chapter.

Before exhaust steam is finally condensed (if it is intended to use it again), a large proportion of the oil may be caught and withdrawn from it by means of oil catchers or separators, consisting of vessels fitted with baffle-plates, against which the steam strikes in passing through; much of the oil condenses on the plates together with some water, and remains in the vessel until drained out. The efficiency of the catchers depends a good deal upon their size; a large vessel slows the speed of the steam and allows more opportunity for both oil and water to condense without being carried

away Oil catchers should not be lagged, as coolness is advantageous.

Filtration of oily water may be effected through flax, jute or sand. Until the filtering medium has become slightly greasy all over it does not filter very efficiently, but oil will cling to oil when it meets it, and is thereby arrested. The flax is cleaned from time to time by blowing steam or boiling water through it the reverse way. Sand is usually washed by a strong reverse current of water, preferably hot.

In all cases where condensed exhaust steam is used as feed water, the boiler should never be blown down without first using the scum cocks freely, so as to remove as much as possible of the grease and scum floating on the water, and boilers fed with such water should invariably be fitted with scum cocks.

Condensed steam which has only been used for heating, or other purposes not entailing contact with grease, may, of course, be returned to the boilers without any of the above precautions.

Marine boilers are no better fitted than land boilers to withstand greasy scale, although it is a common mistake to think that they are, because at sea they are almost always fed with greasy condensed water without a very large proportion of accidents occurring. The reason may be found, not in the form of boiler or the particular kind of lubricant used, but in the superior density of sea water, of which the make-up exclusively consists, and which allows the greasy

matters to continue floating. This is referred to more fully under the head "Sea Water."

5. **Cracking off scale** by sudden expansion or contraction of the scale or of the plates. This is the most objectionable and most dangerous method which boiler-men have yet been able to devise, and has ruined thousands of boilers. It is chiefly resorted to in order to induce employers to believe that the loosening of the scale is due to the efficiency of some worthless boiler composition which the boiler attendant is interested in using, regardless of the risk, amounting almost to a certainty, of straining the boiler seams by the sudden injection of cold water into a hot boiler or of hot steam into a cold boiler. Many leaky joints have arisen from this practice, and it cannot be too strongly condemned.

6. **Purification of the water** by removal of the lime and magnesia before entering the boiler. There can be no question that this is the soundest plan possible, and is only limited in its application by the question of cost. The first outlay for plant is undoubtedly large, and the interest on capital is in many instances more than the annual cost of the softening itself. Against this may be set the fact that a softener will enable a user to employ one boiler (or two) less than would be necessary with hard water, partly because the boilers fed with soft water are kept clean and have more evaporative power, and partly because the stoppages for cleaning are very much reduced.

The cost of the softener is not much more, and is sometimes less, than that of the extra boiler or boilers.

The methods of purification are described in another chapter. It need only be stated here that they are easy, certain and cheap; waters that cannot be softened cheaply are almost invariably so bad that they should never be used at all. The cost of working is in all cases but an infinitesimal percentage on the coal bill, while the savings are by no means small. Steam users who will make careful observation of their coal and water bills, and calculate what hard water costs them for fuel wasted, boiler composition, stoppages and cleaning, chipping, repairs and renewals of boilers, will arrive at the conclusion that the savings effected by softening the water would very quickly repay even a heavy outlay on plant.

When the process of softening enables well or stream water, otherwise useless, to be employed, instead of costly town's water, the saving is so great as to be obvious even to the most careless, and this is again intensified where the town's water itself is hard.

The softening process has, until comparatively recently, been regarded by the public as a delicate and difficult operation, and one requiring a large amount of attention. This was so to some extent, though not so much as was believed, under the old system, by which the carbonate of lime was first removed by means of quicklime, and the sulphate of lime was subsequently removed by a separate process. Many attempts were

also made to effect the softening by means of complex and difficult reactions, sometimes with costly materials which were vastly inferior to the cheap reagents generally employed. A closer investigation of the various reactions has resulted in improved methods, by means of which a single treatment produces the desired result with greater ease and certainty than the old double treatment, and at a still smaller cost. The methods of regulating and proportioning the supply of reagents have also been brought much nearer perfection, and are now so largely automatic as to dispense with the greater part of the attention formerly required.

The softening process is doubly efficacious, as it effects the withdrawal of suspended matters in dirty water, and also renders acid and corrosive waters neutral and harmless.

The present chapter would not be complete without referring to various kinds of water-heating apparatus, which, although not boilers in name, are really so in effect, and are therefore liable to be damaged or rendered inefficient, useless or even harmful by bad water. Such appliances are called "economisers" and "feed-water heaters."

An economiser is practically a preliminary boiler, consisting of a large number of upright cast-iron pipes, and placed in the brickwork flue between the furnaces and the chimney shaft. It is wholly enclosed in a brick chamber, and the hot gases from the furnaces, after passing through and around the boilers, are forced to

pass between and around the economiser pipes. Through these pipes is forced the whole of the feed water on its way from the pumps to the boilers, and while in the economiser it extracts a very large amount of heat from the gases, and enters the boilers at a temperature ranging between 200° F. and 300° F. The effect is, of course, that coal is economised or saved to an extent corresponding to the amount of heat absorbed by the water in the economiser, and this may amount to from 12 to 20 per cent., or even more, according to temperature.

The following table shows the calculated percentage of fuel saved by heating feed water, assuming the boiler pressure to be maintained at 60 lb. The figures give the theoretical saving, on the assumption that the furnaces are constantly stoked in the best possible manner, and to an extent always corresponding to the required evaporation. As a matter of fact, however, furnaces are seldom or never so stoked, and the actual savings are frequently found to be in excess of the theoretical figures. The mere fact that he has not to put so much coal in, will often enable or induce a fireman to be more careful with what he does put in, to distribute it better, and to pay more attention to properly cleaning the fires. The high temperature of the feed also enables a boiler to make steam more quickly, that is to say, to evaporate more water without forcing; and forcing is always uneconomical, for the time being, no matter what kind of boiler is used. The actual waste from forcing is also minimised, as the higher temperature of the furnace

PERCENTAGE OF SAVING OF FUEL BY HEATING FEED WATER.

Steam at 60 lb.

Final Temperature.	Initial Temperature of Water, Fahrenheit.												
	32	40	50	60	70	80	90	100	120	140	160	180	200
60	2·39	1·71	0·86										
80	4·09	3·43	2·59	1·74	0·88								
100	5·79	5·14	4·32	3·49	2·64	1·77	0·90						
120	7·50	6·85	6·05	5·23	4·40	3·55	2·68	1·80					
140	9·20	8·57	7·77	6·97	6·15	5·32	4·47	3·61	1·84				
160	10·90	10·28	9·50	8·72	7·91	7·09	6·26	5·42	3·67	1·87			
180	12·60	12·00	11·23	10·46	9·68	8·87	8·06	7·23	5·52	3·75	1·91		
200	14·30	13·71	13·00	12·20	11·43	10·65	9·85	9·03	7·36	5·62	3·82	1·96	
220	16·00	15·42	14·70	14·00	13·19	12·33	11·64	10·84	9·20	7·50	5·73	3·93	1·98
240	17·79	17·13	16·42	15·69	14·96	14·20	13·43	12·65	11·05	9·37	7·64	5·90	3·97
260	19·40	18·85	18·15	17·44	16·71	15·97	15·22	14·45	11·88	11·24	9·56	7·86	5·96
280	21·10	20·56	19·87	19·18	18·47	17·75	17·01	16·26	14·72	13·02	11·46	9·73	7·94
300	22·88	22·27	21·61	20·92	20·23	19·52	18·81	18·07	16·49	14·92	13·37	11·70	9·93

gases is not merely utilised in the boiler flues but also affects the economiser, the water in which rises and falls in temperature at the same time as the furnace gases.

It is obvious that economisers should be large enough to prevent the hot gases from entering the chimney shaft at a higher temperature than about 250° F., when the boilers are working at their normal rate, and the best economy is attained when they are reduced below 212°. This is not unfrequently the case, as the water is fed into the economiser at the part nearest the chimney shaft, and there both water and gas may be well below 200°, while at the hot end the water may be at 300° and the gas at 600°. Most economisers are furnished with means for easily ascertaining the temperature at both ends, and if readings are regularly taken they form an excellent check upon the firemen. It is a fact which few employers thoroughly grasp, that a really good fireman will keep a boiler at full pressure with 10 per cent. less coal than a lazier or less intelligent man. Firemen ought to be actually *taught* how to fire economically with various kinds of coal. At present not one man in twenty gets anything near the best possible result even with the coal which he is most accustomed to, while if the kind of coal be changed he is all abroad with it for a long time.

Economisers have a further effect which, although at first a partial advantage, becomes afterwards

a serious disadvantage. Much of the mineral impurities in the water, generally only carbonate of lime or of magnesia, is precipitated while in the pipes. A very large proportion of the precipitate falls to the bottom, whence much of it is blown out from a mud valve. The vertical position of the pipes favours the easy withdrawal of the deposit, and of course the quantity of deposit in the boilers is to that extent lessened, and further economy is therefore effected by keeping the boiler cleaner than it would otherwise be. But a portion of the precipitate adheres to the pipes and gradually forms a hard scale and chokes them up. As this scale accumulates the economiser is able to do less work, failing to pick up the proper amount of heat, and allowing more deposit to be formed in the boilers, and at length a time arrives when the pipes *must* be cleaned out. If the scale is very hard and thick, it frequently cannot be removed without breaking the pipes (cast iron being brittle), and new ones must be put in. This is a costly process, but it is absolutely necessary and in the end economical. The very choking of the tubes, although undesirable in itself, is evidence of the work they are doing, and only very bad waters can prevent economisers from repaying their cost with interest.

Economisers are almost universally used in the north of England, where coal is cheap, and yet they are comparatively infrequent in London and the south, where coal is so dear that it would be thought that

steam users would be almost driven into using them. No doubt this is partly due to the fact that the water in the south is usually hard, and economisers fed with it are more difficult to keep clean than with the softer moorland water of the north. But the hard water can almost invariably be softened at a merely nominal cost. When soft water is used for the feed the pipes will not choke, the water will consequently be heated to the highest possible degree; the boilers will not scale, and fuel will thereby be largely saved; the hot feed water will preserve the boilers from the strains to which the plates and seams must naturally be subjected by the injection of cold water, and the whole steaming system will be at its absolute best for economy, reliability and lasting efficiency.

Feed-water heaters utilising exhaust steam are not so efficient as economisers, because the temperature of exhaust steam is much lower than that of the waste gas from the furnaces, being only about 212° F. If the exhaust steam has a free outlet, so as to cause no back pressure on the engines, its temperature will be below 212°, and any excess over this degree is an indication of back pressure on the engines, which is, of course, detrimental to their efficiency. It is therefore very essential when fitting up a water heater to see that it affords ample passage room for the steam, otherwise any advantage gained by heating the feed water will be counterbalanced by loss of power from back pressure. It is therefore obviously a mistake to

put down a small heater and force all the exhaust steam through it. If the steam way through a heater is small (and especially when the steam tubes are spiral or coil-shaped) only a portion of the steam should be made to pass through it, and the rest should pass through an extra outlet capable of being opened or narrowed at will. It is practically impossible for the steam heaters to raise the feed water above 212° except by severely choking or throttling the exhaust; and it may be taken as a general rule that if the feed water is heated above 200°, the exhaust is too much choked and back pressure is created.

Feed-water heaters are much smaller than economisers, and can therefore be used in places where there is absolutely no room for an economiser. They suffer, however, from the same drawback, namely, they are very liable to choke up with scale made of carbonate of lime or carbonate of magnesia. Some of the best are provided with mud chambers and mud valves, by which a good deal of the softest deposit may be blown out; but by far the greatest part of their cleaning is effected by the alternate heating and cooling of the tubes, which cracks off a good deal of the scale by the expansion and contraction of the metal. The little pieces of scale are then blown out through the mud cock or removed through a hand hole. These means are only partially successful, and the heater must from time to time be taken to pieces and cleaned out thoroughly. This is a job which is always put off

until it becomes an absolute necessity in order to allow water to pass through it at all. Now it cannot be too well remembered that there is a point where the loss from back pressure balances the gain from heating the water; and this point varies somewhat in various cases, but may generally be fixed as that where the feed water is only raised 60° F. As soon as a heater fails to raise the water more than 60° above the initial temperature, the heater is causing as much loss as gain, and should at once be cut off and cleaned out. If it cannot then be cleaned out, it should yet be thrown out of action and the exhaust allowed to escape unchecked.

When condensing engines are employed, the feed-water heater is still available, and is placed in a bye-pass or shunt, so that only a portion of the steam passes through it on its way to the condenser. It is a good thing to heat the water with exhaust steam even when an economiser is used, as an economiser works better with warm water than with cold, and is not then so liable to condense the moist vapours in the gases; such moisture invariably absorbs sulphurous acid from the gases, and corrodes the iron pipes. Warming the water first will almost entirely prevent this. When exhaust steam is not available for this purpose, the usual plan is to run a small pipe from the hot end of the economiser back to the suction pipe of the feed pump. Thus a small stream of boiling water is continually running into the cold feed water in sufficient quantity to warm it to the desired temperature.

Scale in heaters is of course prevented by softening the feed water, and the efficiency of the heaters is thereby maintained. But when hard water is used, the heavy scale and deposit is so certain to occur that some heater makers, unable to stop it, try to claim it as a merit, and call their machines "feed-water heaters and purifiers." This is impudently misleading. Boiler makers might as well· claim that their boilers are purifiers because they scale up.

The inconveniences attendant on tubular feed-water heaters are intensified when the boilers are themselves of the tubular type. They are of two kinds, the multitubular or locomotive boiler, in which the furnace gases pass through small tubes placed horizontally in the boiler, while the water circulates round them; and the tubulous or water-tube boiler, in which the water is contained in the tubes, while the furnace gases pass around and between them. Both types are very rapid and economical steamers, comparing very favourably in these respects with the Lancashire type, but they have some disadvantages peculiar to themselves. They hold only half as much water as Lancashire boilers of the same evaporative power. This is not of itself any disadvantage, and is frequently the reverse, but the soluble salts in the water become concentrated much faster, and the water needs changing oftener. As there is much more surface for the fires to heat, so there is also more for scale to form upon. In the locomotive boiler the scale is formed on the outside of the tubes,

and can therefore crack and fall down, which is an advantage, but if the pieces of scale are large and the space between the tubes small, the scale will lodge across and gradually fill up the spaces altogether. Of course this never happens upon railways, where the boilers are washed out very often—every day in many cases—but stationary multitubular boilers are very apt to choke up in this way; the water is then unable to circulate in the boilers, which rapidly decrease in efficiency, while the tubes thus put out of action are very liable to burn through.

Water-tube boilers are differently affected. The scale forms on the inside of the tubes. If very soft and loose the tremendously rapid circulation of the water may carry it away, and it may ultimately settle down in the mud drum and be blown out. But what once sticks to the tubes cannot move again; the scale may indeed crack, but being on the inside and not in a vertical position it cannot possibly fall. It must therefore accumulate, not only on the heating surface but chiefly on the hottest (i. e. the under) portion of it. And as hard scale cannot be removed from the inside of the tubes except by boring it out, it must at any cost be kept soft. Boiler composition makers reap a golden harvest from water-tube boilers.

The dangers connected with steam boilers have caused the development of a new branch of the insurance business. There are now several insurance companies which, for fixed and reasonable premiums,

undertake the periodical inspection of boilers, examine and test them, as well as engines, at regular intervals, and insure the owners against collapse and explosion. As owners are personally responsible under several Acts, for the reasonably safe condition of their boilers, and are liable for damages resulting from a contrary condition, the most thoughtful of them naturally prefer to pay to have their responsibility and risk of loss shifted on to the shoulders of experts who devote their time to the prevention of such accidents.

The oldest, and we believe the largest, of these companies has now over 40,000 boilers under its supervision, in addition to a large number of engines, which it also inspects and insures against breakdown. As its methods and rules are also adopted by the other companies, so far as the extent of their business and organisation allow, it will be useful for steam users to know what the company undertakes and what means it adopts to carry out its undertakings.

The policies cover the holders against the following risks:—

1. Explosion of boiler or collapse of flues or tubes.

2. Damage to surrounding property of whatever description, arising from explosion of boiler or collapse of flue.

3. Claims for personal injuries resulting from the above causes.

4. Where a thorough examination of a boiler can be made at least once a year, the owner's pecuniary

reponsibility under the Boiler Explosions Act, is also covered.

No arbitrary conditions are imposed, and the rates are exceedingly moderate. Each insured boiler is examined at intervals of three or four months, one examination every year being entire and thorough. Resident inspectors are stationed in the principal centres of industry in the kingdom, enabling them to inspect in any town at a minimum cost. Each inspector has a certain number of boilers for inspection, and receives a special bonus at the end of the year if there has been no accident with any boiler under his supervision, thus inducing thoroughness of examination.

In the case of engines the inspection takes place regularly, and diagrams are taken at intervals of three or four months, while a thorough examination of the bearings and working parts is also made once a year. The insurance covers all damage to the engine in the shape of actual breakage or partial fracture of any of the principal parts, if such breakage or partial fracture is so serious as to necessitate the stoppage of the engine. Inspection of engines without insurance is also undertaken; this of course forms a great protection for owners.

Apart from the purely monetary aspect of insurance, it cannot be too strongly urged that careful periodical and efficient inspection is the only reliable means of preventing accidents, and this is exactly what

the system of boiler insurance supplies. It is a much more perfect system than life insurance; to do equivalent work, the life assurance companies would have to keep a large staff of doctors who would periodically visit the insured, examine them, and advise as to their exercise, diet, sanitary arrangements and other details. At present life insurance companies do not do this. By and bye it is quite likely that they may.

It must here be mentioned that there are two or three slight difficulties attaching, in particular cases, to softening feed water for boilers. They are chiefly connected with the use of soda. In locomotive boilers the amount of soda used must be very limited, so that the water shall not be appreciably alkaline, as strongly alkaline water foams a good deal and will make wet steam. This is also the case with water-tube boilers, but to a much slighter extent. With Lancashire boilers the difficulty practically ceases to exist. If the water in the boilers is strongly alkaline with carbonate of soda, the brass or gun-metal fittings will be slightly attacked and corroded. With an excess of caustic soda, which is rare, this occurs to a smaller extent. Gauge cocks and other boiler fittings should not be packed with asbestos where the water is alkaline, as soda dissolves asbestos. Steam pipes also should have copper joints, not asbestos. The copper is in any case the better joint, and where there is any priming or wet steam from alkaline water it should invariably be adopted.

But soda in a boiler cannot attack or corrode the iron itself.

When boilers are fed with softened water by means of injectors, there should always be a pump as a stand-by, as some injectors are very delicate in their working and are apt to refuse to work. It should be mentioned here that for boiler feeding, an injector which takes a large quantity of steam is quite as good and quite as economical as one which requires a smaller quantity. None of the steam or of the heat is lost, and it is an established fact that the circulation and consequent duty of a boiler is positively improved by the preliminary heating of the water, due to the steam mixed with it by the injector. An injector which takes much steam is also less sensitive to dirt, etc., than one which takes less.

CHAPTER III.

WATER FOR MANUFACTURING AND TECHNICAL PROCESSES.

Washing fabrics.—When soap is used with hard water, a large proportion of it is destroyed by the lime and magnesia contained in the water, which combine with the fatty portion of the soap and form a greasy, insoluble and useless curd. The lime salts in a thousand gallons of water will destroy 1·7 lb. of the best hard soap for each degree of hardness of the water, and this is all clear waste, as it is in addition to the dissolved (but not destroyed) soap that the washing process actually requires. In addition to this loss, the insoluble curded soap remains in the water until it comes in contact with the fabric that is being washed, when it naturally sticks to or in the fabric, and owing to its greasy nature cannot be removed from it by rinsing even with hot water. Rinsing with cold, hard water may even increase the damage, as part of the good soap still contained in the fabric will become curded by the hard water and remain there.

Some idea of the loss occasioned by the employment of hard water will be gained from the fact that

London water requires on an average 20 lb. more soap per thousand gallons than the soft water supplied to Bradford, Manchester or Glasgow. At 2*d.* a pound, this amounts to a loss of 3*s.* 4*d.* per thousand gallons, or about five times the price of the water itself.

To save some of this waste, the water is frequently partially softened by means of washing soda (carbonate of soda), which is added to the hard water by rule of thumb, and in quantities that are sometimes insufficient and sometimes too great, in the latter case making the water harmfully alkaline. If such water is used for cleaning woollens the results are serious. Now in any case the usefulness of carbonate of soda is limited. Firstly, it does not precipitate carbonate of lime from water unless it is added in very large excess. Secondly, when used to remove sulphate of lime, the water must be boiling, or precipitation will not take place. In fact whenever carbonate of soda is used, boiling is absolutely necessary, and really does most of the work. Thirdly, the precipitate still remains suspended in the water and never settles out at all.

Lime will do more good work in cold water than soda will do even in hot water, and at a cost so far below that of soda as to be merely nominal. One pound of lime will soften more water than 4½ lb. of soda crystals, and at a twentieth of the cost. Yet even soda is cheap compared with soap.

Soda is detrimental to fine linen fabrics, such as shirts, collars, lace and fine dresses, and cleaners

therefore frequently wash such things with hard water, which must of course be softened with soap. A large proportion of this is precipitated as a greasy curd, which gets into the fabrics and cannot be removed by rinsing, but remains, and is in due course treated with the hot iron, giving a disagreeable dirty colour or spottiness. Laundry owners are aware that their success depends very greatly on the satisfactory colour and appearance of their starched and ironed work, even when it forms only a small portion of the entire wash; the use of soft water for these goods becomes therefore much more important than at first appears.

The soap destroyed by waters of various hardness is approximately as follows:—

Hardness.	Soap per 1000 gallons.	Cost of soap at 2*d.* per lb.
degrees.	lb.	*s.* *d.*
5	8·5	1 5
10	17·0	2 10
15	25·5	4 3
20	34·0	5 8
25	42·5	7 1

Where water softening has been adopted in a laundry, it must be remembered not merely that it is not necessary to use as much soda as before, but that the quantity *must be reduced*, otherwise the excess will give the linen a yellow colour. In such a case it is worse than useless to add more blue than usual; the excess

of blue will cause markings in the folds of the linen. The remedy is simply to use less soda, and in many cases when the water has once been softened, only soap is required in the washer.

For washing cloth the importance of soft water is very great. The washing processes between weaving and dyeing have to be very thorough and prolonged, and the time occupied is much shorter when soft water is used, while there is a considerable difference in the feel of the cloth afterwards. The cloth washed and rinsed in soft water is soft and smooth to the touch, and takes the dye well and evenly, while that treated with hard water is harsher, and the grease remaining in it from the soap prevents the dye from being properly absorbed. It is not for nothing that the woollen industries are concentrated in the soft-water districts.

Goods prepared for dyeing should be scoured with soft water during at least all operations involving the use of soap. The precipitated earthy soaps adhere so tenaciously to the fibre that they cannot be removed by ordinary processes. In the scouring of wool or of silk they render the fibre more or less impermeable to the dye, so that neither mordant nor colouring matter can be afterwards properly fixed thereupon, and irregular development of colour results.

In the actual dyeing processes, hard water has frequently the effect of dulling the colours obtained from many colouring matters, both during the dyeing and in the subsequent washing. Professor Hummel, in

pointing out the effects of various impurities in water, says*: "In some cases earthy soaps may act injuriously by playing the rôle of mordants. Water rich in earthy bicarbonates is not suitable for the solution of many of the coal-tar colours, such as methyl violet, etc. A portion of the colour base is precipitated as a tarry mass, and goods dyed in such solutions are apt to be spotted. Ferruginous impurities are also very objectionable in dyeing operations. The iron being usually present as bicarbonate, acts upon soap solutions after the manner of the analogous calcium and magnesium compounds, and similar, or even worse results ensue. In wool-scouring, cotton bleaching, and other operations where alkaline carbonates are used, ferric oxide is precipitated upon the fibre. With such goods it would be impossible to dye bright colours subsequently. Bleached fabrics acquire an unpleasant yellowish tinge, and are rendered quite unsaleable.

"Water containing alkaline carbonates is frequently met with. Such water is by no means detrimental to wool scouring, but for purposes of mordanting, dyeing, and washing off dyed goods, it is, if possible, more injurious than the water containing earthy carbonates. It must for such operations be carefully neutralised with sulphuric or acetic acid."

Cases are instanced, however, where hard water is positively advantageous in dyeing operations. The matter is too complex to let any hard and fast rules be

* 'Dyeing Textile Fabrics,' by J. J. Hummel, F.C.S.

laid down; each case must be determined by experts, and the treatment of the water must be based upon an intimate knowledge of the process and of the dye-stuffs used. In any case it is apparent that a soft pure water is the best basis to start from. If lime is required for the dyeing bath, it can be added; if prejudicial, it is withheld.

In tanning and dressing leather, water plays the part of a chemical agent in several operations, and where the lime process is employed for unhairing the hides, the effect of impure water is important. After the skins have been thoroughly soaked in lime water, they have absorbed a large quantity of it, and have afterwards to be steeped and washed thoroughly in fresh water in order to remove the lime. Now if the fresh water contain bicarbonates of any kind, or carbonic acid, it will, instead of removing all the lime, precipitate some of it, and the skin will be thoroughly permeated with carbonate of lime, which will remain in the pores. And if the orifices of the pores be stopped up with this carbonate of lime, the elimination of the lime still remaining in the caustic state in the interstices of the tissue is impossible until plunged in the tanning solution, when both chalk and lime combine with (and consequently destroy or waste) the tannin, forming tannate of lime. This must itself be removed from the hide, to allow more tannin to gain access to the hide, and the result is that more tannin is needed, and a much longer time.

In the preparation of the tanning solution, the carbonate of lime in the water and in the skins, and also the caustic lime in the skins, have the effect of neutralising the tannic and gallic acids of the bark, and forming an insoluble and useless tannate of lime. This is all waste, and as it remains in or adheres to the gelatine, it affects the power of taking dyestuffs afterwards.

Many experiments have been made with the view of ascertaining the different effects of hard and soft waters during the process of plumping. The results are not so concordant or so conclusive as to enable them to be relied on. But of course if the "plumping" water contains bi-carbonates, chalk will be precipitated in the skins at the commencement of the liming process as well as afterwards when rinsing. This effect is avoided in the more recent method of unhairing by means of soda, but the cost is much higher than that of the lime process.

For paper making clear water is required, but its hardness is of less importance provided there is no appreciable quantity of iron. Iron, however, will cause discoloration of the paper. It can be easily precipitated and removed by means of lime.

Distilling is to some extent affected by the water. The fermentation proceeds more rapidly and completely with soft water than with hard. When the water is drawn from a stream it usually contains organic impurities, and although the spirit may be in nowise injured by them, still they are found to so greatly

prevent formation of alcohol that the quantity obtainable from the same weight of grain is much less than when purer water is employed. Condensers become coated with deposit from hard chalky water, with the result in some cases that, owing to sluggishness in cooling, the specific gravity of the condensed liquor is different from what it should be, and may injuriously affect the quality of the spirit.

CHAPTER IV.

THE CHEMISTRY OF WATER SOFTENING.

The successful methods of softening water may be shortly described as—

1. The lime process (called the Clark process).
2. The soda process.
3. The combined lime and soda process.

The lime process, invented sixty years ago by Dr. Clark, is applicable to waters containing bicarbonate of lime and bicarbonate of magnesia, and consists in adding to such water a definite proportion of hydrate of lime (usually in solution as lime water), which combining with the carbonic acid present (either free or combined as bicarbonate) in the hard water is precipitated in the form of the insoluble mono-carbonate of lime, while the soluble bi-carbonates of lime and magnesia, having thus lost half their carbonic acid, are reduced to the insoluble mono-carbonates and are also precipitated, The chemical reaction is as follows :—

(*a*) $CaO, 2(CO_2) + CaH_2O_2 = 2(CaO, CO_2) + H_2O,$

(*b*) $MgO, 2(CO_2) + CaH_2O_2 = MgO, CO_2 + CaO,CO_2 + H_2O.$

There is reason to suppose that in the case of carbonate

of magnesia the action is sometimes pushed further thus—

$$(c)\ MgO, 2(CO_2) + 2(CaH_2O_2) = MgH_2O_2 + 2(CaO, CO_2) + H_2O.$$

As the hydrate of magnesia is insoluble, the useful effect of (*c*) is the same as that of (*b*), but it evidently allows of a little latitude in the quantity of reagent added, without materially altering the results.

The lime process does not remove the sulphate of lime or affect it in any way. It does decompose sulphate of magnesia, precipitating the insoluble hydrated oxide of magnesia, but it leaves an equivalent quantity of sulphate of lime in its place, so that the water is thereby unimproved, or even deteriorated, inasmuch as sulphate of lime is in nearly all cases more objectionable and harmful than the sulphate of magnesia. The reaction is—

$$MgSO_4 + CaH_2O_2 = MgH_2O_2 + CaSO_4.$$

There are one or two technical processes, chiefly dealing with brine or sea water, in which the removal of the magnesian salts is usefully effected by means of lime, and the lime salts are separately removed by subsequent treatment. These processes do not, however, fairly come within the scope of this book: their object is not really the purification of the water but of the salt. In the purification of water the employment of the lime process is limited to the removal of

bicarbonates in cases where there is no important quantity of sulphate of lime or sulphate of magnesia. These latter must be treated with soda.

The soda process is a variable one, the carbonate of soda and the hydrate of soda (caustic soda) being employed either singly or together. Carbonate of soda added to water containing sulphate of lime or sulphate of magnesia, with little or no carbonic acid or bicarbonates, reacts upon the sulphates and decomposes them, forming carbonate of lime or of magnesia, which being insoluble is precipitated, while the neutral and inert sulphate of soda remains in solution. The reactions are—

(*a*) $CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$;
(*b*) $MgSO_4 + Na_2CO_3 = MgCO_3 + Na_2SO_4$.

The reaction is sluggish, more especially in the case of magnesia, and requires the aid of heat to complete it quickly; this is not generally available, and to this extent carbonate of soda falls short of satisfaction. The presence of free carbonic acid or of bicarbonates also interferes with the desired reaction, thus—

$$CaSO_4 + CO_2 + Na_2CO_3 = CaO,2(CO_2) + Na_2SO_4.$$

Instead of carbonate of lime, bi-carbonate is formed, and remains in solution. If the water be heated, the extra atom of carbonic acid is driven off, and the monocarbonate of lime is precipitated.

Caustic soda is more energetic than carbonate of

soda, and frequently produces sufficiently good results without heat. It is usually assumed that as soon as it enters water containing carbonic acid or bi-carbonates (and water which contains bi-carbonates always contains some free carbonic acid) it absorbs carbonic acid, becoming carbonate of soda, and then reacts upon the sulphate of lime or magnesia, as explained above. Further on we give reasons for believing that this assumption is not altogether correct. It is true that unless carbonic acid be present caustic soda is of no use for removing lime salts, because the hydrate of lime is freely soluble, but it is otherwise as regards the salts of magnesia, of which the hydrate is insoluble. Caustic soda (hydrated oxide of sodium) reacts upon sulphate of magnesia, precipitating hydrated oxide of magnesia, and leaving sulphate of soda in solution. We believe it reacts upon sulphate of lime in the same way, producing the soluble hydrate of lime, which then combines with the carbonic acid in the water and is precipitated as carbonate of lime, thus—

(1) $CaSO_4 + CO_2 + 2NaHO = CaH_2O_2 + CO_2 + Na_2SO_4$;

(2) $CaH_2O_2 + CO_2 = CaO, CO_2 + H_2O$;

or putting it shortly, looking only at results—

$$CaSO_4 + CO_2 + 2NaHO = CaCO_3 + H_2O + Na_2SO_4$$

Any bi-carbonate of lime or of magnesia which has thus been deprived of half its carbonic acid will of

course also be precipitated as carbonate, so that the caustic soda is capable of double softening action, thus—

$$CaO, 2(CO_2) + CaSO_4 + 2NaHO = 2CaCO_3 + Na_2SO_4 + H_2O.$$

But if carbonic acid be present in excess, bicarbonate of lime will remain in solution. This consideration leads directly to the third process.

The combined lime and soda process is employed when the hard water contains sulphates of lime and magnesia, and also carbonic acid or bicarbonates in such proportion as to prevent the proper quantity of soda from having its complete softening effect. The method is to add as much soda as will effect the decomposition of all the sulphates of lime and magnesia present, together with as much lime as will absorb all the carbonic acid not withdrawn by the soda reactions. Thus—

(*a*) $CaO, 2(CO_2) + CO_2 + CaSO_4 + CaH_2O_2 + 2NaHO = 3CaCO_3 + Na_2SO_4 + 2H_2O.$

(*b*) $2[CaO, 2(CO_2)] + CaSO_4 + CaH_2O_2 + 2NaHO = 4\,CaCO_3 + Na_2SO_4 + 2H_2O.$

(*c*) $CaO, 2(CO_2) + CO_2 + MgSO_4 + 2CaH_2O_2 + 2NaHO = 3CaCO_3 + MgH_2O_2 + Na_2SO_4 + 2H_2O.$

These reactions may be multiplied almost indefinitely according to the proportions of salts and acids in the water, but practically there is no difficulty presented,

the proportions and quantities of lime and soda being varied accordingly. This process is therefore adapted to almost all waters which are not satisfactorily treated with lime or with soda alone. In the above formulæ we have shown only hydrate of lime and hydrate of soda, but in most cases carbonate of soda may be employed instead of the hydrate, the proportion of hydrate of lime being increased to correspond. The work done is not quite so rapid or so complete, but when the quantity of soda required is but small, carbonate of soda is generally used because it is easier to handle and measure than the hydrate.

In the foregoing we have referred only to the bicarbonates of lime and magnesia, and the sulphates of lime and magnesia. The bicarbonate of iron is affected in exactly the same way as bicarbonate of magnesia, while the chlorides and nitrates of lime and magnesia behave like their sulphates. The characteristics and properties of the various oxides and salts of lime and magnesia may here be separately considered.

LIME (Quicklime, Oxide of Calcium, CaO).

Quicklime is prepared by heating carbonate of lime (marble, limestone or chalk) in actual contact with flame, so as to drive off the carbonic acid with which the lime is combined. That made from marble is purest, but it is too expensive for any but laboratory use.

The purest commercial lime is what is called Buxton lime, and is made from white limestone. It slakes rather slowly, and breaks up partly into exceedingly fine powder, and partly into large grains which do not dissolve completely in ordinary water.

Grey lime is made from the grey chalk beds. It slakes to a fairly fine powder, and although not so pure as the Buxton lime, it carries little waste.

Chalk lime is made from white chalk, oolite, and soft limestone. It contains a larger quantity of small stones than either Buxton or grey lime, but it slakes very well and with great rapidity.

Lias lime should not be used for water softening, as its hydraulic properties, which make it so excellent for building purposes, make it undesirable for lime-water, as it is too liable to set in water, owing to the clay which it contains.

Quicklime absorbs or combines with water in the proportion of three parts of lime to one part of water, by weight, becoming what is called "slaked lime" or "hydrate of lime," the absorption being accompanied by considerable heat, while the lumps of lime at the same time crumble to a fine powder. The powder is finer if a much larger quantity of water has been used than the lime is capable of absorbing, but the operation is much slower. Lime slakes slowly under water, because the water takes up the heat generated during the operation and so cools the lime. The fine powder tends to become coarser and granular if left for

some time with an excess of water, and as it then settles more rapidly after stirring, lime should be well slaked before being used for making lime water.

The bulk of fully slaked "fat," or pure lime, in powder, is about two and a half times that of the original lime. Poorer lime does not swell so much nor form so fine a powder.

Quicklime will become slaked by absorbing moisture from the air. Lime so slaked absorbs carbonic acid at the same time as water, and when fully slaked may contain as large a proportion as 57 per cent. of carbonate of lime, and only 43 per cent. of hydrate of lime. Such a mixture is useless for making lime water.

Lime, or rather the hydrate, is sparingly but definitely soluble in water. It is less soluble in hot water than in cold, so that a cold saturated solution will throw down a precipitate when heated. The solubility at various temperatures is as follows, in grains per gallon—

32°F.	80	quicklime = 106	hydrate of lime	
60° F.	70	„ = 92·8	„	„
210° F.	40·5	„ = 53·6	„	„

Lime does not dissolve rapidly, and in preparing a saturated solution a large excess of lime must be used, the surplus being allowed to settle before the lime water is drawn off.

The strength of lime water is tested by means of

a standard solution of acid. Lime water is strongly alkaline, turning red litmus to blue, methyl orange to lemon yellow, turmeric (yellow) to reddish brown, and phenolphthalein (colourless) to purple pink. The strength may also be tested, but much less exactly, by the soap test. Both tests are explained in another chapter.

Slaked lime gradually absorbs carbonic acid from the atmosphere, becoming carbonate of lime, which is chemically the same as chalk. Lime water does the same, but more rapidly, and the chalk being insoluble, the precipitate, which is only formed at the surface of the water, becomes a solid film on the top, if it be at rest, or falls to the bottom if in motion. This power of absorbing carbonic acid (CO_2) is utilised in the softening process.

Lime is capable of decomposing the acid salts of magnesia and iron, as well as of other metals which need not be specifically referred to here. This property is of importance when dealing with waters containing sulphate of magnesia and chloride of magnesium as well as carbonates.

Milk of lime is also, but more rarely, used in softening, but it is simply a mixture of lime and water of indefinite strength, varying from minute to minute. Milk of lime does not admit of that accuracy of proportion which is so easy to obtain with lime water. In dealing, however, with very foul waste waters, such as those from tanneries, dye works, and

acid effluents, the proportion of lime required is frequently too great to allow of mere solution, and milk of lime is then employed.

CARBONATE OF LIME (Chalk, Marble, $CaCO_3$).

Carbonate of lime consists of 56 parts by weight of lime combined with 44 parts of carbonic acid. It is only slightly soluble in pure water. Authorities are not agreed as to its exact degree of solubility, but it may be briefly stated that a solution made by shaking for a considerable time a large excess of finely powdered chalk in pure water (free from CO_2) will contain up to two grains per gallon and no more; while a solution made from a stronger solution of bicarbonate of lime, the excess being precipitated by means of heat or lime, will contain three grains or more per gallon. If either solution be raised to a temperature of 300° F., it will deposit practically the whole of the carbonate of lime.

Carbonate of lime is rather more soluble in a cold solution containing even a small quantity of chloride of sodium, and the presence of this salt occasionally prevents total softening. The same effect is noticed if some other impurities are present, but the effect is strongest when the water contains an appreciable amount of vegetable matter.

Carbonate of lime dissolves much more freely in water containing carbonic acid, and as most natural

waters, including rain water, contain carbonic acid, it follows that if they percolate through, or remain in a layer or bed of chalk or limestone, they will dissolve some of it, the amount varying chiefly according to the quantity of carbonic acid present in the water. This may be considerable, as carbonic acid is more soluble in water than any other common gas, with the exception of sulphuretted hydrogen. The relative solubilities at 60° F., are—

Hydrogen	1·9
Oxygen	2·9
Nitrogen	1·5
Air	1·8
Carbonic oxide	2·4
Carbonic acid	100·0

It is believed and even treated as a known fact that the carbonic acid (CO_2) combines with the chalk ($CaCO_3$) to form a definite compound [CaO, 2 (CO_2)], which is called bicarbonate of lime. This compound, although its existence has been demonstrated almost to absolute proof, is so unstable that it has never been separated or obtained in a solid state. If the solution be heated above 170° F., the bicarbonate of lime is gradually decomposed, one-half of the carbonic acid being driven off; the same thing occurs to a less degree on prolonged exposure to the air. If hydrate of lime or solution of lime be added to the cold solution of bicarbonate of lime, the latter readily parts with one-half of its carbonic acid, which combines with the lime, forming carbonate of lime. Now the carbonate of lime left by the decom-

position of the bicarbonates is insoluble, as is also that formed by the recombination of the carbonic acid with the lime, and *both* are precipitated, with the exception of about three grains per gallon, the quantity which water will keep in solution. To carry out the reaction thoroughly, sufficient lime must be used to combine not only with the carbonic acid in combination as bicarbonate, but also with the appreciable quantity of uncombined or "free" carbonic acid which such waters invariably contain.

Carbonate of lime may also be precipitated by absorbing the extra carbonic acid with caustic soda (forming carbonate of soda, which is soluble and may be utilised for further reactions as explained further on), or with caustic baryta (forming the insoluble carbonate of baryta), or with caustic potash (forming the soluble carbonate of potash which can be further utilised), or with oxide of magnesium (itself insoluble and forming an insoluble carbonate of magnesia). All these four methods have been tried by various experimenters, but that with caustic soda is the only useful one. Caustic potash is good but too expensive; caustic baryta is unreliable, expensive and poisonous; oxide of magnesium is very expensive and gives very poor results. The caustic soda process is practical, and often used with great success if sulphate of lime or magnesia be present.

There is a physical, although not a chemical difference between the carbonate of lime precipitated cold

and that precipitated hot, the latter being in larger and heavier crystals which settle rapidly if the water be at rest.

The insolubility of carbonate of lime is still further utilised in water softening, as the sulphate of lime and the chloride of calcium, which cannot themselves be precipitated, may be decomposed by alkaline carbonates, carbonate of lime being formed and precipitated.

It is the practice in some localities to clarify dirty water by adding sulphate of alumina either in the shape of commercial sulphate of alumina [$Al_2(SO_4)_3$, 18 Aq], containing about 15 per cent. of alumina, or as ordinary alum [$Al_2(SO_4)_3$, K_2SO_4, 24 Aq], containing less than 11 per cent. of alumina. As the efficiency of the reagent depends upon the percentage of alumina it contains, it is evident that the commercial sulphate of alumina is preferable, being not only much cheaper per ton, but also much more efficient weight for weight. The reaction which takes place is this: The sulphuric acid (SO_3) combined with the alumina displaces the carbonic acid of the carbonate of lime dissolved in the water, leaving sulphate of lime in solution (which of course will scale boilers heavily), the alumina being precipitated as hydrate of alumina in flocculent gluey masses which stick to or envelop the particles of dirt or organic matter in the water, and on settling drag them down altogether, leaving the water clear. This reaction can only take place when the water contains an

alkali to combine with the sulphuric acid, and so release and precipitate the alumina. Carbonate of lime and carbonate of magnesia being alkalies will effect this decomposition, but sulphate of lime and sulphate of magnesia will not. When the water does not naturally contain any alkali, the alumina must be precipitated by the addition of caustic soda or carbonate of soda, and this is the better method to adopt in any case when the water is used for boilers or washing, as it prevents the formation of the objectionable sulphate of lime. In this case the clarification by alumina may take place at the same time as the softening process, and in the same vessels. It may here be observed that alumina in small quantities, such as one or two grains per gallon, will not settle rapidly or well unless precipitated carbonate of lime or magnesia is also present to give it weight.

SULPHATE OF LIME ($CaSO_4$).

GYPSUM ($CaSO_4 + H_2O$).

Hydrated sulphate of lime is sparingly soluble in water, the solubility being, like that of sulphate of soda, greatest at 95° F. Its solubility at different temperatures is—

At 32° F.	.. ..	143	grains per gallon.
68°	.. ..	168	„ „
95°	.. ..	178	„ „
212°	.. ..	152	„ „
284°	.. ..	58	„ „
324°	.. ..	42	„ „

It is much more soluble in a cold solution of chloride of sodium, its solubility at 65° F. varying with the density of the solution as follows:—

Spec. grav. ..	1·014 ..	301 grains of $CaSo_4$ per gal.	
	1·034 ..	423 „	„ (maximum)
	1·113 ..	301 „	„

The only case in which such densities are obtained is that of brine pumped from underground salt deposits.

Sulphate of lime is nearly insoluble at the temperature of boiler water at 50 lb. pressure and over, and is precipitated in heavy crystals which cohere solidly and form a continuous scale of very great hardness. It remains where it is formed or first settles and is not disturbed by the convection or circulating currents which keep the carbonate precipitate so long in suspension.

In a steam boiler, the precipitation of sulphate of lime will not necessarily begin at any given pressure or temperature, but will depend also upon the degree of concentration. If a hard water containing 7 grains of hydrated sulphate of lime per gallon be evaporated, the sulphate of lime will precipitate when it passes the saturation point corresponding to the temperature; if the latter be 284° F. (38 lb. pressure), the saturation point will be 58 grains per gallon, which is arrived at when the boiler has evaporated about 7½ times its capacity of water, being constantly re-filled but not blown down. At 324° F. (80 lb. pressure), saturation takes place on evaporating only five times. To prevent

precipitation of sulphate of lime, the boiler must be regularly blown down to an extent corresponding to the amount of sulphate of lime in the water. For example, waters containing varying proportions of sulphate of lime require that the boilers at 80 lb. pressure should be blown down as follows, with—

1	grain	per	gallon,	1	gallon	for every	40	gallons pumped in
2	„	„		2	„	„	40	„ „
5	„	„		5	„	„	40	„ „

and so on in proportion.

In many cases such a proportion will be much too costly, inasmuch as the water blown out contains valuable heat, and the loss of heat may well be more expensive than the presence of scale.

A Lancashire boiler in regular work will evaporate about seven times its own working capacity in a week of 56 hours. If the water contains 5 grains of sulphate of lime per gallon, it will precipitate by concentration unless the boiler is blown down during the week to the extent of its own capacity. The value of the heat so blown out would be about eight shillings, equivalent to about 3½ per cent. of the total amount of the weekly coal bill. The cost of soda to remove the five grains of sulphate of lime in a softening apparatus, would be about eighteen pence per week. But this comparison is not complete, as there are other reasons for blowing down boilers, just as there are other reasons for softening hard water.

The precipitation of sulphate of lime does not

complete itself immediately the solution reaches the requisite temperature. As in the case of the carbonate of lime, it is a very gradual process, and it would even appear that continuous heating is not necessary, but that the gradual precipitation goes on even after the source of heat has been removed and the temperature has fallen to that of ordinary air. In an experiment made by Professor Storer at Syracuse, N.Y., a quantity of brine was heated in a small closed boiler during five minutes to 143° C. (289° F.). On allowing the liquor to flow out at this temperature it was very cloudy from suspended sulphate of lime. One portion of it was then filtered while hot, another portion after it had become cold, and in both instances the clear filtrate became clouded in the course of a few minutes, and at the end of twenty-four hours had deposited a large quantity of sulphate of lime.

Precipitated sulphate of lime is gradually redissolved when the water cools, but this process is slower the higher the temperature at which precipitation took place. When the deposit is formed at 300° F., it takes several days before it is redissolved, even if the quantity is small relatively to that of the water.

Sulphate of lime in solution, allowed to remain for any length of time in contact with organic matters, such as cork, bark or vegetable fibre, is reduced to sulphide of calcium, which in the presence of carbonic acid is converted into carbonate of lime, with liberation

of sulphuretted hydrogen. Samples of water, and especially of dirty water, should therefore be analysed as soon as possible after they are taken, otherwise they may show a false proportion of carbonates. If a sample of dirty water cannot be analysed for several days after being taken, it is best to filter it before putting it into the bottle. It is true that its character is thus slightly altered, but not to anything like the same extent as would happen without filtration. It may be taken as generally true that any sample which smells of sulphuretted hydrogen when uncorked, has suffered decomposition while in the sample bottle. If the water smells of sulphuretted hydrogen *before* being bottled, a note to that effect should always be sent to the analyst.

To remove sulphate of lime it must be converted into carbonate of lime. This is done by means of carbonate of soda (Na_2CO_3), the soda (Na_2O) combining with the sulphuric acid (SO_3) of the sulphate of lime, forming sulphate of soda, which is soluble, neutral and inert in boilers or with soap, while the CO_2 combines with the lime and forms a precipitate of carbonate of lime. The reaction is as follows :—

$$CaO, SO_3 + Na_2O, CO_2 = CaO, CO_2 + Na_2O, SO_3.$$

The carbonate of soda may be added as such to the water, but if there be free carbonic acid present the carbonate of lime formed (or a corresponding portion of it) will become bicarbonate of lime and will not precipitate. This may be avoided by adding lime-water suffi-

cient to absorb the carbonic acid; or caustic soda may be employed, which will itself absorb carbonic acid and so become carbonate of soda, enough lime-water being added to absorb the remaining carbonic acid, if any. Caustic soda used thus acts more quickly than carbonate of soda, and has a more powerful effect, probably because it really decomposes the sulphate of lime, forming sulphate of soda, and liberating hydrate of lime to absorb carbonic acid, which it does very readily indeed. The first reaction would be—

$$CaO, SO_3 + 2NaHO + CO_2 = CaH_2O_2 + CO_2 + Na_2SO_4,$$

the hydrate of lime and carbonic acid then combining thus—

$$CaH_2O_2 + CO_2 = CaCO_3 + H_2O.$$

There are several reasons for supposing that this double reaction actually takes place. If caustic soda be added to a cold saturated solution of sulphate of lime, in the absence of carbonic acid, no precipitation takes place, because the hydrate of lime we assume to be formed is itself soluble to almost the same equivalent extent as the sulphate, that is to say, a saturated solution of hydrate of lime contains as much CaO as a saturated solution of sulphate of lime. But if the solution be heated to boiling point, there will be a very copious precipitation, not of the sulphate, but of the hydrate of lime, as at that temperature the hydrate of lime is far less soluble. Again, if a strong solution of

the very soluble chloride of calcium be employed, the caustic soda will precipitate hydrate of lime copiously, even when cold. The reaction is quite analogous to that with sulphate of magnesia, from a solution of which the insoluble hydrate of magnesia is precipitated by caustic soda.

When carbonate of soda only is used, in quantity calculated equivalent to that of the sulphate of lime present, the reaction will not complete itself in any reasonable time without the aid of heat. This fact is explicable in the light of the preceding paragraph; it is evident that the carbonate of soda cannot turn sulphate of lime into hydrate of lime, and is too weak an alkali to force the total exchange of acids without assistance of some kind.

CHLORIDE OF CALCIUM ($CaCl_2$).

This is not the same as the well-known chloride of lime or bleaching powder. It is seldom present to any important extent in natural waters. Its removal is effected in exactly the same manner as that of sulphate of lime, the reaction being commonly given as—

$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl.$$

Its physical properties are, however, entirely different. It is so soluble that 1 lb. of water at ordinary temperature will dissolve 4 lb. of chloride of calcium, while the solubility becomes still greater with rise of tempera-

ture. It is therefore evident that its presence in a boiler will not cause incrustation or deposit. It has, however, one objectionable property, namely, that when concentrated at a high temperature it has a tendency to be decomposed by contact with metal, as in the case of iron, the latter combining with the chlorine and thus dissolving away. This is not more than a tendency under peculiar circumstances which can very seldom occur, and even the tendency has been denied. The only property of chloride of calcium which need concern us is that of decomposing sulphate of magnesia when heated in solution with it. The two substances, harmless when separate, recombine into two most objectionable new salts, namely, the sulphate of lime, which causes hard scale, and the chloride of magnesium, which decomposes and corrodes the boiler plates. The question is one of importance when sea water is concerned, and is referred to later under that head.

NITRATE OF LIME ($CaNO_6$).

Nitrate of lime rarely occurs, and is even then of no consequence except in presence of sulphate of soda or sulphate of magnesia, when exchange of acids takes place, with precipitation (in boilers) of sulphate of lime. Nitrate of lime is very soluble indeed, and causes no scale or corrosion. It is decomposed and precipitated as carbonate of lime by means of carbonate of soda, in exactly the same manner as the sulphate and chloride.

CARBONATE OF MAGNESIA ($MgCO_3$)
Magnesite.

Also found as basic carbonate or subcarbonate of magnesia (magnesia alba [$3(MgCO_3)$, $MgH_2O_2 + 3Aq$]), but this form is seldom, if ever, found in natural waters, and in this work it is assumed that we have only to deal with the ordinary carbonate.

Carbonate of magnesia behaves in exactly the same manner as lime, and is soluble or insoluble to practically the same extent. Their properties are so parallel at all temperatures that the preceding remarks regarding the carbonate of lime may be applied equally to carbonate of magnesia. It is worthy of notice, however, that while a gallon of water will hold dissolved (in absence of carbonic acid) three grains of carbonate of lime *or* three grains of carbonate of magnesia, it will not, under ordinary conditions, hold simultaneously three grains of each. Water treats them as identical. This is perhaps because the crystals of the two substances are identical in shape and solubly equivalent.

The salts of magnesia are not generally turned into carbonate of magnesia in the softening process, but into the hydrated oxide. This hydrate, unlike that of lime, is even less soluble than the carbonate. In boilers there is frequently, or even generally, a certain quantity of oxide of magnesia in the scale, although none was contained in the water. This is because the carbonate

of magnesia is decomposed and the carbonic acid driven off at high temperatures, such as those to which plates and scale are subjected, without actual contact with the flame, therein differing from carbonate of lime.

SULPHATE OF MAGNESIA (Epsom Salts, $MgSO_4$).

Sulphate of magnesia is very soluble in water, 10 lb. of cold water dissolving 3 lb. of it. Its solubility is also much increased by rise of temperature, and it is not liable by itself to cause any scale or deposit in boilers, although further on it will be shown that it has some action in this direction when in company with certain other substances. Nor is it corrosive or destructive to boiler plates, so that by itself it has practically no effect in a boiler. It does not even cause priming to any appreciable extent; but it very much hinders the removal of lime salts, and may thereby make itself exceedingly objectionable. This has already been mentioned when speaking of quicklime, where it was stated that its presence impedes the application of the lime (or Clark's) softening process pure and simple, by reason of the formation of sulphate of lime. An example will make this point clearer. Let us take a water containing—

Carbonate of lime	.. ..	10 grains per gallon
Sulphate of magnesia	..	10 „ „

The hardness, as indicated by the soap test, will be about 18 degrees, but its scale forming-power in a boiler will only be 10 grains per gallon, due to carbonate of lime. If the water be treated with lime, to remove the carbonate of lime, we may get rid of seven grains of carbonate of lime, while the sulphate of magnesia will be decomposed, magnesia hydrate will be precipitated, and sulphate of lime to an equivalent extent will remain in solution. The water will then contain—

Carbonate of lime	.. ..	3 grains	per gallon
Sulphate of lime	.. ..	11 „	„

The hardness will be about 11 degrees by the soap test, but the scale-forming power will be 14 grains per gallon, as against 10 grains before treatment, while the resultant scale will be much harder than that made by the untreated water.

In such a case as the preceding, soda must be used to decompose the sulphate of magnesia. The decomposition of sulphate of magnesia by carbonate of soda is different from that of sulphate of lime. When treated cold, the precipitate is a mixture of carbonate of magnesia, hydrated oxide of magnesia, and water, having the composition—

$$4\,(MgCO_3),\ MgH_2O_2 + 9\ Aq.$$

When the solution is boiled, the greater part of the water is driven out, and some of the carbonic acid, and the precipitate becomes $3\,(MgCO_3),\ MgH_2O_2 + 3\ Aq.$ The second kind of precipitate is less soluble than that

first described, which explains the superior results obtained by treating magnesian waters hot. Caustic soda is a better precipitant than the carbonate of soda, as it produces the highly insoluble hydrate of magnesia; this is generally mixed, when treated cold, with some of the more soluble carbonate and hydrate mixed precipitate first described, owing to the presence of carbonic acid in the water; but if the water is treated boiling, the precipitate is nearly pure hydrate. Instead of using caustic soda, carbonate of soda may be used with the addition of sufficient lime-water to combine not only with the carbonic acid in the water, but also with that in the carbonate of soda, which is thus partially caustified, but this method is inferior to the caustic soda process, and rarely gives such good results.

Under extreme pressures, such as may soon be expected in steam boilers of the tubular types, a fresh complication may be looked for. Carbonate of lime and sulphate of magnesia at a temperature of 200° C. or 392° F. (225 lb. steam pressure) react upon each other, carbonate of magnesia and sulphate of lime being formed, giving a double precipitate.

Sulphate of magnesia in solution may be decomposed by chloride of sodium, but only at low temperatures. The fact needs no further comment. The solid salts decompose at a red heat, liberating hydrochloric acid. It is not absolutely impossible for this to occur in a boiler. We have seen hard scale a foot thick composed of about 50 per cent. sulphate of lime, 40 per

cent. chloride of sodium and 10 per cent. sulphate of magnesia. This form of scale was due partly to concentration, and partly to lack of circulation, owing to want of heat at the bottom of the boiler, where the scale lay.

CHLORIDE OF MAGNESIUM ($MgCl_2$).

Chloride of magnesium is removed from water in the same way as the sulphate of magnesia, and by the same reagents, chloride of sodium remaining in solution, and magnesia being precipitated either as hydrate or as carbonate, according to the form of soda employed, caustic soda being the best. In solubility it is nearly equal to chloride of calcium, 2 lb. being dissolved by 1 lb. of cold water. It cannot therefore itself scale boilers, but unfortunately it possesses a corrosive power such as to render it more prejudicial than any other natural impurity in boiler feed water. At all boiler pressures or temperatures it decomposes on coming into contact with iron, magnesia being precipitated, while the chlorine attacks and dissolves the iron. If the iron be coated over with carbonate of lime, the latter will be a protection, as the chlorine will attack the lime instead of the iron. But a coating of scale is seldom sufficiently continuous to protect all the iron, as scale is liable to crack, and the iron thereby exposed is at once attacked until covered by new scale. The softening process prevents this corrosive action, as the soda employed

combines with the chlorine and forms chloride of sodium (common salt), which does not attack iron nor decompose. But it may happen that a hard water containing some chloride of magnesium may be only partially softened, and the boilers fed with that water may begin at once to corrode, although not corroding with the hard water. This is because they had had so thick or so continuous a coating of scale from the hard water as to be protected from the corrosive action of magnesium chloride. Partially softened water would neither maintain the old coating intact nor furnish a new one, and as chloride of magnesium is absolutely the last salt to be decomposed in the softening process, it would be present in the water and would find all the plates open to attack. In such a case the boiler must be protected by the use of more soda or of more lime.

Chloride of magnesium is decomposed by lime, hydrated oxide of magnesium being precipitated and chloride of calcium remaining in solution. Provided that there is no sulphate of magnesia remaining in the water so treated, the chloride of calcium will not give rise to scale or deposit, and is not objectionable. There are, however, very few cases where chloride of magnesium can usefully be treated with lime alone, and practically only soda is used for this purpose.

CARBONATE OF IRON ($FeCO_3$).

Carbonate of iron, when present in solution, is always in the state of bicarbonate, being dissolved by carbonic acid. Some waters are very strongly charged with it. Upon standing, the bicarbonate of iron, which is an extremely unstable substance, loses carbonic acid rapidly, and simultaneously absorbs oxygen, becoming the ordinary red oxide of iron or iron rust. If such water is used without softening, it should first be splashed and sprayed over bundles of twigs or by other means, so as to expose it to the air and allow the precipitating and oxidising effect to be expedited. Some waters, more especially from mines, are so highly charged with iron that a few seconds' spraying is sufficient to turn it rusty red, and produce a large quantity of iron deposit.

Carbonate of iron presents little difficulty in treatment, and is precipitated by means of lime or soda at least as readily as carbonate of lime. The reaction is more complex, to be sure, as the bicarbonate of iron becomes carbonate of iron on removal of one half of its carbonic acid. If no further chemical be supplied, this carbonate of iron loses carbonic acid, absorbs oxygen, and is precipitated as sesqui-oxide of iron. But this process is slow, and the settlement of the precipitate is slower still. The addition of a larger quantity of lime absorbs all the carbonic acid, precipitating the iron as

hydrate; this reaction is very rapid, and the hydrate of iron settles with corresponding rapidity.

The hydrate of iron absorbs further oxygen very fast, and all iron precipitates obtained in softening water became ultimately the red sesqui-oxide (iron rust). The intermediate reactions are many and complex, but as they all have the same result they need not be further referred to.

Other salts of iron are, practically speaking, never found in natural water. The iron salts, when in solution, are all very unstable, rapidly absorb oxygen, and turn to oxide of iron, which is insoluble in water.

SILICA (Silicic Acid, Oxide of Silicon, SiO_2).

Silica is contained in almost every water. In hot springs it is present in considerable quantities, but in cold waters its quantity is not important; it is then generally in combination with alumina; the total amount is seldom more than a quarter of a grain per gallon, and is of little or no importance.

SEA WATER.

Sea water contains many impurities, some of which are of little consequence here. It is extremely hard, owing to the large quantity of lime and magnesian salts it contains. Professor Vivian B. Lewes gives the follow-

ing analysis of a sample of sea water and of the scale deposited from it:—

	Sea water. Grains per gallon.	Scale percentage.
Carbonate of lime	3·9	0·97
Sulphate of lime	93·1	85·53
Carbonate of magnesia	trace	nil.
Sulphate of magnesia	124·8	nil.
Chloride of magnesium	220·5	nil.
Chloride of sodium	1850·0	2·79
Silica	8·4	1·10
Oxide of iron	trace	0·32
Hydrate of magnesia	nil	3·39
Moisture		5·90
	2300·7	100·00

It will be noticed that while the scale contains far less carbonate of lime than would be expected, it contains a considerable proportion of hydrate of magnesia, and also an appreciable quantity of oxide of iron. These two last are evidently partly the result of decomposition of magnesium chloride and re-combination with other substances. The reactions are very complex, but appear to be as follows. If any iron is exposed, the chloride of magnesium attacks it, throwing down magnesia hydrate, and dissolving the iron as chloride; the latter is then decomposed by any carbonate of lime present, the result being carbonate of iron and calcium chloride. Carbonic acid is driven off from the carbonate of iron by heat, precipitating oxide of iron. In addition to the chloride of calcium so far obtained, it is possible that some has also been formed by the direct action of the chloride of magnesium on the carbonate of

lime. Now chloride of calcium changes acids with sulphate of magnesia, sulphate of lime being formed and precipitated, while chloride of magnesium is again left in solution, undiminished. It will, thus be seen that of all the impurities named, the chloride of magnesium is the only one which (although really doing the mischief) remains unweakened and unaltered in quantity. This is a very important point, as it explains the very extensive damage that may be caused by a very slight amount of magnesium chloride. It also explains how a water containing carbonate of lime and sulphate of magnesia can make a scale including hydrate of magnesia and sulphate of lime, the magnesium chloride being capable of effecting the change almost indefinitely, owing to the regenerative action of the cycle. *But* sulphate of magnesia in sufficient quantity is an absolute essential to the completion of the cycle of reactions, otherwise the chloride of calcium first formed undergoes no further change.

It has been pointed out elsewhere why condensed exhaust steam should not be returned unpurified to the boilers. The objection is, however, minimised if the boilers are fed exclusively with sea water. For in this case the water in the boilers gradually becomes so dense from concentration of salt that the greasy scum, made by the oil and sulphate of lime adhering together, will not sink, and does not therefore attach itself to the tubes. It has been argued: "Marine boilers are constantly fed with greasy condensed exhaust on board ship without

collapsing—why not use marine boilers on land with condensed steam, as they work so well with it at sea?" The reply is that the practice is made possible, not by any particular kind of boiler, but by the density of sea water. And even with sea water great care must be taken. The density of the water must be carefully maintained. The scum cocks should be used continually to remove the greasy scum, and engineers should be careful, on coming into port, never to blow out the dense water and fill up with light unless the scum has previously been thoroughly removed. Neglect of this rule has frequently led to mysterious cases of collapsed tubes the next time steam has been raised.

Sea water cannot be softened for use in steam boilers by any practical chemical process. The chemicals (caustic soda and carbonate of soda) necessary to remove all the sulphate of lime and the sulphate and chloride of magnesium, would cost between three and four shillings per 1000 gallons (a price of course impossible), and even at that cost the purification could not be completed without boiling under pressure.

The only practical method of purifying sea water is by boiling it *under high pressure* in a closed vessel or preliminary boiler, through which all the feed would have to pass on its way to the boilers. This would to a great extent precipitate the sulphate of lime, and the precipitation might in some degree be hastened by the addition of some carbonate of soda; the utility of

the latter is open to doubt however. As the heated water would be fed directly into the boilers there would be little loss of heat. The chief objections to this method are two—the heating vessel will require very frequent cleaning, which may not often conveniently be given, and the objectionable chloride of magnesium is not only not removed, but, owing to the decreased quantity of scale, has a better chance than before to attack the boiler plates and tubes. The advantages of the method are scarcely weightier than the disadvantages, and we are inclined to prefer to pin our faith to careful and frequent scumming and blowing down, while keeping up the density of the water.

Sea water interests us, however, in another way. All tidal rivers, such as the Thames at London, the Tyne at Newcastle, the Mersey at Warrington, and many others, are contaminated more or less by sea water, and it is the variable proportion of the latter which is so difficult to deal with. The Thames may be instanced as typical.

Thames water above Battersea can at most times be efficiently softened at a cost of one penny per thousand gallons; at the top of extra high tides the percentage of sea water is appreciable, and the cost rises to twopence or more. The four hours of flood are especially to be avoided, if possible, but the remaining eight hours will generally give good water. Between London Bridge and Chelsea the water is only tolerable

during the six hours of lowest tide, the other six hours being bad. Below London Bridge the period of good (or land) water becomes very short, and at Woolwich can scarcely be said to exist. The top of the tide at and below London Bridge may be at once condemned as unfit for use; it *is* actually used a good deal, for the low water is extremely filthy, and moreover is difficult to get, but its scaling and priming qualities really make it much more costly than company's water. Canals and docks fed from the Thames below London Bridge can of course only be filled at high tide, and their water is invariably bad.

Oily water is not actually hard water, but its effect in steam boilers is so similar to that of scale (but greater), and the methods of its purification so similar to that of softening hard water, that we have included the latter in this chapter.

In exhaust steam condense the oil is present chiefly in the form of globules so tiny and so diffused through the water as to form an emulsion resembling soapy water. The globules are too small to rise to the surface, and can pass through filter paper and cloth without being arrested, even by the closest and thickest fabrics.

The methods successfully adopted entail the formation of a precipitate uniformly through the water. The precipitate absorbs or clings to the oily particles, and subsequent removal of the precipitate entails the removal of the oil. The precipitate may be either—

Carbonate of lime
Carbonate of magnesia
Hydrated oxide of magnesia
Hydrated oxide of alumina
Hydrated oxide of iron

or a mixture of several of these. They are all equally efficient if formed in sufficient quantity, but as lime and magnesia salts are mostly absent from condensed exhaust steam, alumina is usually precipitated as the absorbent.

The most usual methods of obtaining the alumina (or iron) precipitate are:—

1. By mixing sulphate of alumina in the oily water and precipitating by the addition of—

(*a*) Hard water containing carbonates.
(*b*) Lime water.
(*c*) Soda, either as carbonate or as caustic.

2. By electrolysis, a continuous current of electricity being sent through the water while it is passing between electrodes. If the positive electrode be of iron, a hydrate of iron is formed which acts upon the oil. If the positive electrode be of aluminium, a hydrate of alumina is formed with similar effect. The current has also a separate distinct effect upon the oil, which tends to hasten the coalescence of small globules into larger ones, but this is not necessarily advantageous as the larger globules are less easily absorbed than the small ones.

Comparing the results and costs of the different methods—

No. 1.

(*a*) is the cheapest.

(*b*) is very cheap, and slightly more efficient.

(*c*) is still cheap, and most efficient, as no re-hardening of the water takes place during the process.

No. 2 is the most expensive, owing to the consumption of electric current, but where the cost of current is negligible, as in electricity generating works, this objection is outweighed by the fact that no chemicals are employed; on the other hand the filtration is more difficult than with the chemical process. The process is very rapid. Its efficiency depends largely upon the amount of current employed and also upon the plates being kept clean. The plates of course disappear under the process.

It should be observed that this process has no effect upon bacteria nor upon the scaling or other salts present in the water, which is no softer than before treatment. As a rule the process lends itself chiefly to the withdrawal of oil from steam condense, especially in electric light stations where the cost of the current absorbed is not noticeable.

CHAPTER V.

REAGENTS FOR SOFTENING AND CLARIFYING WATER.

The principal reagents are quicklime, caustic soda, carbonate of soda, aluminate of soda, sulphate of alumina, potash alum, and sulphate of iron. These are all in successful use, and may be used with confidence in proportions suited to the circumstances. Other reagents which have been tried, but without the same success, are baryta, chloride of barium, oxide of magnesium, carbonate of magnesia, carbonate of lime, and (although not for softening) hydrochloric acid. *None of these can be recommended.*

To assist in the preparation of the softening solutions, tables are given of their respective solubilities and the strength of various solutions. It must be remembered that in *every* case a precipitate is formed in the dissolving tank, and means must be adopted to ensure that this precipitate shall not choke up the cocks or nozzles by which the rate of outflow is regulated.

The proper strength of the lime-water used is *saturation point*, and as the temperature is almost always close to 60° F., the usual strength of the saturated solution will be 70 grains of lime or 92·8 grains of hydrate of

SOLUBILITY OF LIME IN WATER.

Temperature.	Quicklime. Grains per gallon.	Hydrate of Lime. Grains per gallon.
32° F.	80	106·0
60°	70	92·8
80°	66	87·5
100°	62	82·1
212°	40·5	53·6

lime per gallon. Tested with acid, 5 c.c. of lime-water should be neutralised by 11¼ c.c. of $\frac{N}{50}$ acid (that is to say, acid one-fiftieth the strength of what is known among chemists as "normal acid"). A large excess of the solid lime must be stirred up with the water for some length of time in order to produce saturation, and if the lime-water is appreciably weak it shows either that too little lime has been stirred up in the water, or that the stirring has been insufficient, or that the lime is old and too much spent, for quicklime mixed with a considerable quantity of stones and precipitated chalk will not make saturated lime-water. Should the lime-water be appreciably over strength, it has not been allowed sufficient time to settle after the stirring, the extra strength being due to floating particles of solid lime.

Lime-water is easily made in quantities of, say, 500 gallons at a time, by stirring slaked lime by hand with a paddle in a cistern of water for from ten to fifteen

minutes. If larger quantities are needed, some mechanical mixing arrangement must be provided, as it is practically impossible to stir a large tank sufficiently well by hand. The best method is to make the lime-water continuously by means of a steadily revolving stirring device, fresh water being added at the inlet while lime-water flows from the outlet. The lime-water must be free from suspended particles of lime, or its strength will be increased, and unsatisfactory results may be obtained. An arrangement for making saturated lime-water continuously is shown on page 124, and is one of those used with the Stanhope system. The water which is to be saturated with lime, descends through a central pipe to the bottom, is there thoroughly churned up with lime by the revolving paddles, and then ascends, clearing as it rises, and arrives saturated but clear at the top of the tower, whence it overflows into the mixing compartment of the softening tower. For this arrangement the proportion of the lime-water to the hard water is automatically graduated by the simplest possible arrangement. This is an ordinary cistern, fitted near the bottom with two cocks or nozzles, the larger to pass the bulk of the hard water, while the small portion which is to be made into lime-water passes through the lesser one. The two cocks are adjusted until the correct proportions of outflow are obtained, and are kept so. The head of water in the cistern is kept constant by means of a ball valve, and, if a perfectly regular quantity of water is wanted, this is the

best arrangement But if the supply is a fluctuating one the head of water will fluctuate also, the normal height being about half full. The increase or decrease of height will affect the flow from both cocks equally, and the proportion will remain constant. Moreover, if the supply of water ceases altogether, the supply of lime-water also ceases simultaneously; this is very important.

When hand-mixing is employed, two lime tanks may be required, the clear lime-water in one being used while the other is being filled, stirred and allowed to settle. When the first is empty its outlet cock is shut, that of the second being opened instead. The empty tank has a small charge of slaked lime put in, is filled up with water, well stirred, and is left to settle. The lime-water is drawn off from the top level by means of a float, supporting a flexible tube fitted to the outlet cock, the reason being that the lime-water is clearest near the top, and the lower portion has further time to clear while the upper portion is being used. Lime-water forms a thin film or crust of chalk where exposed to the air, and for this reason any small cock by which its rate of flow is regulated is apt to choke and so alter the speed.

It is therefore best to use an automatic proportional measuring device by means of which a definite quantity of raw water (say 20 gallons) is mixed with a definite proportion of reagent (say $1\frac{3}{4}$ gallons) without the use of any nozzles at all. Such an arrangement is shown in Fig. 5.

In lime tanks and lime towers alike there is a good deal of precipitate, and these must be cleared out regularly. In the vertical lime towers this is easily done by means of a mud cock at the bottom. In the lime tanks the deposit on the flat bottoms must be swept towards a mud cock placed at the side, or baled out with a scoop or pail. In both tanks and towers a peculiarity of lime manifests itself and necessitates some degree of waste. The lime has a tendency on being stirred to roll itself into tiny globules or balls; the outer part of these balls is, of course, dissolved away, but they gradually become coated with chalk formed by absorbing carbonic acid from the water. As soon as the chalk coating is nearly complete, the ball becomes inert and useless, and has therefore to be flushed out with the stones and other waste. For this reason a considerable excess of lime must be put in at each charge, and the importance of lime being fresh and uncoated will be obvious. This does not entail difficulty when once the point is clearly understood, but until it is understood, there is a constant tendency to be sparing of the lime and to keep it down very near the theoretical quantity. It should be quite double.

Owing to the varying qualities of caustic soda used by different experimenters, none of them appear to agree as to the correct strength of solutions of varying density. The following table is based upon the experiments of Richter.

STRENGTH OF CAUSTIC SODA SOLUTIONS.

Specific Gravity.	Nearest Degree. Beaumé.	Percentage of Caustic Soda.	Lbs. of Caustic Soda per gallon.
1·01	1·5	1·05	0·106
1·02	3	2·07	0·211
1·03	4·5	3·07	0·316
1·04	6	4·02	0·418
1·05	7	4·97	0·521
1·06	8·5	5·89	0·624
1·07	10	6·81	0·727
1·08	11	7·69	0·830
1·09	12	8·57	0·932
1·10	13·5	9·43	1·037
1·11	16	10·28	1·140
1·12	16	11·10	1·243
1·13	17	11·92	1·350
1·14	18	12·81	1·460
1·15	19	13·76	1·582
1·16	20	14·73	1·710
1·17	21·5	15·73	1·840
1·18	22·5	16·73	1·974
1·19	23·5	17·72	2·109
1·20	24·5	18·71	2·245
1·21	25·5	19·69	2·382
1·22	26·5	20·66	2·520
1·23	27·5	21·62	2·660
1·24	28·5	22·58	2·800
1·25	29·5	23·52	2·941
1·26	30·5	24·47	3·083
1·27	31	25·40	3·226
1·28	32	26·33	3·370

STRENGTH OF CAUSTIC SODA SOLUTIONS—*continued.*

Specific Gravity.	Nearest Degree. Beaumé.	Percentage of Caustic Soda.	Lbs. of Caustic Soda per gallon.
1·29	33	27·24	3·515
1·30	34	28·16	3·661
1·31	35	29·06	3·807
1·32	36	29·96	3·955
1·33	36·5	30·82	4·099
1·34	37	31·67	4·244
1·35	38	32·40	4·374
1·36	39	33·08	4·500
1·37	40	33·75	4·625
1·38	40½	34·41	4·748
1·39	41	35·06	4·869
1·40	42	35·70	4·988

Caustic soda (hydrate of soda) consists of 77·5 parts of oxide of sodium combined with 22·5 parts of water. This is the pure chemical, but it is not made commercially. The usual qualities made contain various impurities, and the different strengths are named from the approximate percentage of oxide of sodium (not hydrate of soda) contained. The commercial grades actually tested are shown on opposite page.

The lowest grade of caustic soda is what is termed "caustic bottoms," and consists actually of the stuff at the bottoms of the vessels in which the caustic soda undergoes its last heating and purification. It contains a large amount of hydrate of soda, but it is mixed with so

large a proportion of insoluble and useless matters that its efficiency is much lowered. The grade ordinarily used is that called "70 per cent. caustic." The high strength caustic soda is of course the best, but its price is higher out of proportion to the increase in strength. It must be remembered that 77½ per cent. caustic is the absolutely pure chemical.

Contain	Caustic Bottoms.	Vat Liquor Cream.	Red Liquor Cream.	60 per cent. White.	70 per cent. White.	High Strength.
Sodium hydrate ..	58·6	74·6	75·0	79·8	89·6	96·0
„ carbonate ..	..	1·4	3·1	1·1	2·4	0·2
„ aluminate ..	5·6	1·3	0·8	0·4	0·2	0·2
„ silicate ..	0·7	0·2	2·1	0·1	0·3	0·1
„ sulphite ..	0·2	0·1	1·5	..	..	..
„ sulphate ..	5·5	2·2	1·5	3·6	3·4	1·5
„ chloride ..	6·1	7·8	6·8	15·1	3·9	1·3
Insoluble	23·0	..	0·2	..	..	..
Water	..	12·3	9·0	..	..	..

Caustic soda is usually sold in iron drums containing about 670 lbs. weight. Smaller drums, containing 112 lbs., are sold at higher prices, but are more convenient to handle. The drums must be cut in two with a cold chisel and hammer to extract the soda. The caustic soda in the drum is solid, but on exposure to the air it absorbs moisture and becomes a soft mush outside to a depth of several inches. It is therefore difficult to break off portions of any particular weight, and of course

its strength varies with the amount of moisture absorbed. Its caustic nature also makes it very dangerous to handle as it very rapidly dissolves the skin. The best method is therefore to dissolve the whole or the half of a drum in a strong iron tank, nearly full of water (the hotter the better), and stir it up. The strength or density of the solution is ascertained by means of an hydrometer, and the required quantity is measured out into another tank, which is then nearly filled up with water, and stirred up. A certain amount of precipitate will be formed in this dilute soda tank, and it should therefore be allowed to settle before being used. The outlet should not be quite at the bottom, but a little higher, so as not to draw off the settled precipitate. The dilute solution will be of constant strength, which may be ascertained, if need be, by means of the acid test described on page 157.

Caustic soda is best dissolved in hot water, and plenty of it. It will dissolve most rapidly if placed upon a perforated plate, some distance from the bottom of the tank, and kept covered with water. The dense solution as it is formed sinks to the bottom and is replaced by more water. If soda or any other solid soluble substance is placed on the bottom of a tank, it will take a very long time to totally dissolve, even if stirred up. Tanks for caustic soda must be of iron, and very well jointed, or the soda will leak through the joints. Cast-iron tanks, cast in a single piece, are best, but cannot be made economically of large size. They should not be painted inside, as soda dissolves oil paint.

Dilute solutions may be contained in galvanised tanks, but strong solutions dissolve the zinc by galvanic action if there be any other metal exposed to the liquid.

If caustic soda is dissolved in even a large quantity of water, it will form a voluminous flocculent deposit, in which is entangled a large quantity of air, and which consequently takes a very long time to settle. But if the caustic soda is dissolved in a comparatively small quantity of water, and the solution is then poured into the bulk of the water, although a precipitate is formed it is of a kind which settles out very much more satisfactorily. For this reason it is best to dissolve the soda before putting it into the dilute solution tank.

Carbonate of soda is made in several forms, and sold under various names. The commonest and weakest is decahydrated carbonate of soda, generally called "soda crystals," "washing soda," or "Scotch soda." The reason for the last name is not very obvious. It is used for all household purposes, as it is the only form well known to housekeepers, is easily kept, easily handled and easily dissolved. Its comparative strength is 34 to 37 per cent. of pure alkali.

Soda ash is the dry impure carbonate of soda from which the pure alkali is afterwards made. Its impurities are many, and vary in amount. It is used in very large quantities for purposes which require a cheap reagent without regard to purity. It is too caustic for household use. It dissolves with extreme difficulty in cold water, and not very rapidly in hot, and cannot con-

veniently be used for cold process. Its strength varies between 60 and 70.

Pure alkali is the purest and strongest commercial carbonate of soda. Weight for weight it is the cheapest and best. Its great drawback is that it dissolves slowly in cold water. Its strength is nearly 100, being over 99. This is often called soda ash.

Crystal carbonate, made by Gaskell, Deacon & Co., is a very pure form; it is the monohydrated carbonate of soda. It is more easily soluble than either pure alkali or soda ash, but not so easily as the washing crystals. It is best dissolved in hot water. Its strength is 82.

Concentrated crystal soda, made by Brunner, Mond & Co., Limited, is also called the sesquicarbonate of soda. It is not a mono-carbonate, as it contains rather more carbonic acid in proportion to the soda. It is, however, practically speaking, carbonate of soda of 70 strength, and has special advantages of its own, more especially for washing wool, woollens and delicate fabrics, as its extra carbonisation renders it less caustic than any other kind, although its useful strength is great. It is more easily dissolved, even in cold water, than any other form, and is particularly suitable for household purposes.

Bicarbonate of soda is never used for water softening. Its strength would be 52, but it would need to be caustified with lime to be of any use, while it is in every other way for this purpose inferior to the other kinds, and is very dear.

The analysis of the ordinary forms of carbonate of soda averages as follows:—

	Soda Crystals per cent.	Crystal Carbonate per cent.	Pure Alkali per cent.
Sodium carbonate ..	34·22	82·90	99·22
„ hydrate ..	0·10	0·	0·
„ sulphate ..	2·54	trace	0·14
„ chloride ..	0·27	trace	0·50
Water	62·84	17·00	0·

Carbonate of soda is best measured by weight, the strength of the solid chemical being known. If it is found more convenient to dissolve a large quantity at once, it must afterwards be gauged by means of a hydrometer, or by the acid test. For the density or hydrometer test, the table on page 114 will be found useful.

Carbonate of soda makes a precipitate when dissolved in hard water, but of a lighter and more powdery kind than that caused by caustic soda, and the outlet cocks or nozzles are not so liable to choke. There is no real advantage to be gained by dissolving it first before putting it into the dilute soda tank, except in the case of the kinds which dissolve only in hot water. Soda crystals and sesquicarbonate of soda may be dissolved while filling up the cistern.

Aluminate of soda is a compound of hydrate of soda and alumina. In the pure form it is too expen-

CARBONATE OF SODA SOLUTIONS.

Specific Gravity.	Soda Crystals, $Na_2CO_3 + 10$ Aq. Lb. per gallon.	Pure Alkali, Na_2CO_3 Lb. per gallon.
1·019	·51	·19
1·027	·72	·27
1·039	1·04	·38
1·059	1·59	·59
1·079	2·15	·80
1·099	2·75	1·02
1·120	3·36	1·24
1·141	3·99	1·48
1·162	4·65	1·72
1·183	5·32	1·97
1·204	6·02	2·23

sive for practical use in softening water. There are cheaper impure forms made, containing a large percentage of burnt clay, which settles out on solution. These cheap grades have no definite guaranteed strength, and no table of strengths can be given. This is one obstacle to the general employment of aluminate of soda, but a greater objection is that the chemical reaction is slow in taking place, and the precipitate formed is slow to settle, so that the softening and clarifying vessels must be of very large size. Theoretically, the cheap aluminate of soda should, for some waters, be an economical reagent, but the practical objections render it much inferior to caustic soda and sulphate of alumina used together.

Sulphate of alumina is sold commercially in several forms and under various names. They are all hydrated, that is to say, the actual sulphate of alumina [$Al_2(SO_4)_3$] is combined with water of crystallisation. What is commercially known as sulphate of alumina contains about 48 per cent. of actual sulphate of alumina, and 52 per cent. of water, a little iron being also present. What is called aluminoferric cake is exactly the same in all essential respects, only of the cheapest kind. Iron does not at all impair its value for clarifying water, and the cheapest qualities are as good as the dearest. The form best known to the public is called alum, or potash alum. It is by far the most expensive kind, and by far the least useful for our purpose, being only two-thirds as strong as the cheap sulphate of alumina, owing to the presence of a large proportion of sulphate of potash, which has to be paid for by weight, but is absolutely inert and useless. In this book the commercial sulphate of alumina alone is recommended and referred to.

Sulphate of alumina can be easily handled, and is therefore best measured by weight. It dissolves very readily in hot water, and pretty well in cold water, a precipitate being formed which must be allowed to settle out before the solution is used. Roughly speaking, the weight of the sulphate of alumina used must be double that of the caustic soda which is added specially for the purpose of precipitating the alumina from it. If iron tanks are used for holding solutions of sulphate of

alumina they are liable to corrosion, as the reagent contains a little free sulphuric acid. The best tanks are of slate, well jointed; but lead-lined wooden tanks are very good and are cheaper. The jointing of the lead lining is best done with burned lead.

Sulphate of iron is not largely used for clarifying water, partly owing to its high price. Its clarifying power is even greater than that of sulphate of alumina, but it has one disadvantage. Should a little of the reagent or of its precipitate remain in the clarified water, it is not safe to use in washing textile fabrics except those to be dyed black, as the precipitate turns red and stains the fabric. This is not the case with sulphate of alumina, of which the precipitate is, and remains, white and cannot stain, while it absorbs dye well and freely, without injuring the colour. Ferrous sulphate (green vitriol) contains 45·32 per cent. of water, and dissolves easily in hot water and fairly well in cold. It is not as good as the ferric sulphate. Ferric sulphate contains no water, and is much less soluble; it must be stirred well in hot water. Mixture with caustic soda or carbonate of soda precipitates ferric hydrate, which settles quickly. Its principal application (so far as concerns us here) is in clarifying polluted waste waters.

It should be noted that although lime water and soda may be mixed together before addition to the water to be treated, and may be contained in the same cistern, sulphate of alumina (or sulphate of iron) must be kept

TABLE OF SOLUBILITIES.

ONE GALLON OF PURE WATER CAN DISSOLVE OF

Substance.	At 60° F.	At 212° F.
Alum (potash alum)	0·95 lb.	35·7 lb.
Aluminium sulphate	3·3 „	8·9 „
Ammonium oxalate	0·45 „	4·08 „
Barium chloride	3·5 „	6·0 „
„ hydrate	0·5 „	1·0 „
*Calcium carbonate	2·5 grains	1·5 grain
„ chloride	40·0 lb.	Unlimited
„ hydrate	93·0 grains	53·6 grains
„ nitrate	40·0 lb.	Unlimited
„ oxide (lime)	70·0 grains	40·5 grains
‡ „ sulphate (hydrated)	161·0 „	152·0 „
Ferrous sulphate	2·0 lb.	17·8 lb.
*Magnesium carbonate	Doubtful	1·5 grain
† „ chloride	20·0 lb.	40·0 lb.
„ hydrate	2·0 grains	2·0 grains
„ oxide	1·4 „	1·4 „
„ sulphate	3·0 lb.	13·0 lb.
Sodium biborate (borax)	0·4 „	5·5 „
„ carbonate (dry)	1·2 „	4·5 „
„ „ (crystals) ..	4·1 „	14·0 „
„ chloride	3·5 „	4·0 „
„ hydrate	6·1 „	Unlimited
„ hyposulphite	5·0 „	20·0 lb.
„ phosphate	1·2 „	..
„ sulphite	2·5 „	10·0 lb.
„ sulphate	1·1 „	4·2 „

* Insoluble at about 290° F.

† Decomposes at boiler temperatures in presence of alkaline earths or iron. ‡ Nearly insoluble at 350° F.

separate from them until actually entering the water, otherwise the alumina or iron would be precipitated in whatever vessel the mixture took place, and would be altogether wasted.

It has sometimes been stated that where sulphate of alumina is employed, it should be added *after* the softening reaction is quite completed, and in a separate vessel, otherwise the different chemicals would not soften; this is quite a mistake. The best results are generally obtained when all the reagents are put into the water simultaneously. The only exception is one in name only; and that is when the lime water and the hard water are mixed with a splash. It is good to mix the water and reagents well, but where alumina is employed there should be little or no splashing, as tiny bubbles of air become entangled in the alumina precipitate, and prevent it from settling freely.

A table of solubilities of various substances in common use, more or less connected with water softening and purification, is given on page 117. The figures show the utmost quantity of the chemical that can be dissolved by one gallon of water at ordinary temperature and at 212° F. The figures do *not* indicate the weight of chemical contained in a gallon of saturated solution.

CHAPTER VI.

CLARIFICATION.

Matters floating or suspended in water may be removed by :—

1. Natural settlement and decantation.
2. Assisted settlement and decantation.
3. Filtration.

The three methods will be considered separately.

Unassisted settlement can be employed when the suspended matters will settle or sink quickly and before decay sets in. Such matters are chalk, sand, and some kinds of earth. Few waters contain sand, those that do being usually well waters rising from a stratum of fine loose sand. As sand generally settles quickly, and is itself quite clean and not liable to decay, settlement in ordinary reservoirs is sufficient. Earths, on the contrary, are seldom of such a nature as to settle completely and quickly, chiefly owing to their admixture with organic matters. Earths which do not contain organic matter settle out well enough ; they are usually composed of silica, alumina, lime and magnesia in various proportions.

Chalk is the usual product of any process of soften-

ing water, and will settle thoroughly if allowed sufficient time, and more especially if the water is in shallow layers. This is what takes place in the reservoirs or settling tanks forming part of the well-known softening arrangements. The original method employed by Dr. Clark, who was the first to soften water practically, was to turn the turbid water into large shallow reservoirs, and allow it to settle for one or two days, by which time the water was perfectly clear. The reservoirs were made in pairs, the clear water being drawn off from one, while the turbid water was clearing in the other. This method entailed a large area for the reservoirs, which had to be cleaned out from time to time, and the chalk mud removed. The reservoirs were succeeded firstly by filter-presses, and subsequently by various forms of settling or clarifying tanks or towers; these latter can be used continuously night and day without stopping, the clarified water flowing away from an outlet at the top, and the chalk deposit being gradually and continually collected at the bottom, and removed by simply opening a mud valve, and without stopping the process. In these towers the water is divided into a number of shallow layers by means of iron diaphragms sloping downwards at an angle of 45°. The whole of the water passes through each shallow division in turn, the chalk gradually settling on the surfaces of the diaphragms and sliding down them to the lower ends, which are provided with means for withdrawing the deposit from the influence of the rising water, and for blowing it through a mud cock

without stopping the working. It is, of course, essential that the deposit upon each diaphragm shall be withdrawn without falling through the rising layers of water below.

In Fig. 2 the diaphragms or shelving plates are perforated with holes in even rows, several inches apart. The chalk deposit slides straight down, between the rows of holes, to the lowest part of each diaphragm, which is not perforated, but forms a pocket in which the deposit lies quiet, out of the influence of the rising water, mud cocks being provided to blow it out. The water, of course, rises very gradually and slowly *through* the diaphragms instead of round them, the very slow pace allowing the deposit to settle well. This form of tower is subject to the disadvantage that, as the mud cocks project outside the towers and are exposed to the wind, they (the cocks) are, in winter, liable to freeze up and burst. This is avoided in the next form, which is the standard for large-sized towers.

In Fig. 3 the diaphragms are cones, with the apex downwards. (If the towers are rectangular, the diaphragms are inverted pyramids.) They are perforated in even rows, each line of holes stretching in a straight line from the upper edge towards the centre, so that the chalk slides down between. The point of each cone is cut off and replaced by a funnel-shaped neck, the lower end of each neck reaching into the neck next below. The lowest neck ends *below* the level of the water inlet. The result is that the whole of the necks form a continuous column

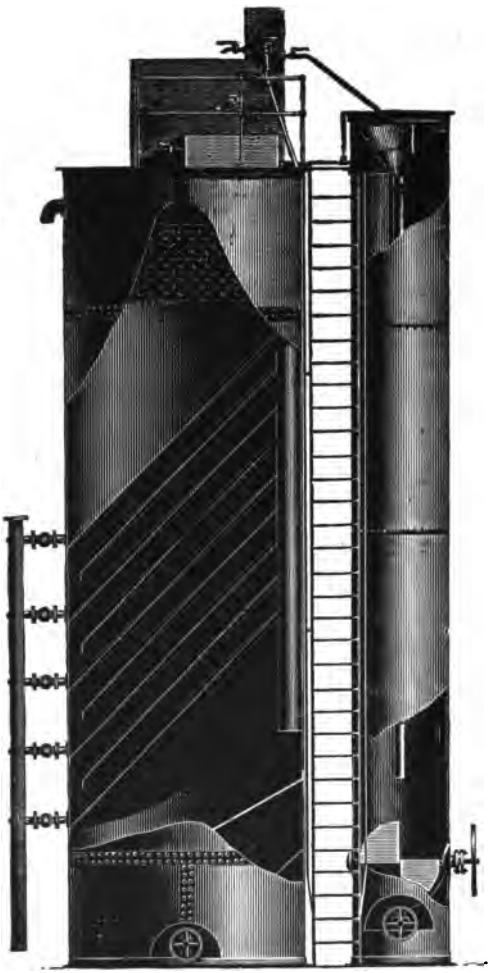

FIG. 2.—COLLET-STANHOPE SOFTENER.

of perfectly still water, so that the chalk deposit from each conical diaphragm falls down freely and undisturbed to the large mud pocket formed by the conical bottom of the tower, the water in the mud pocket being quite still or dead. Only one mud cock is needed, and as it can be placed within the shell-plate of the tower, it is protected from the weather. The desired slow motion of the water is obtained to its fullest possible extent in this tower.

In the apparatus of which Fig. 4 is an illustration, the hard water enters the small

FIG. 3.—STANDEN'S TOWER.

cistern at the top, where the various proportions required for lime water and soda solution are divided off, the

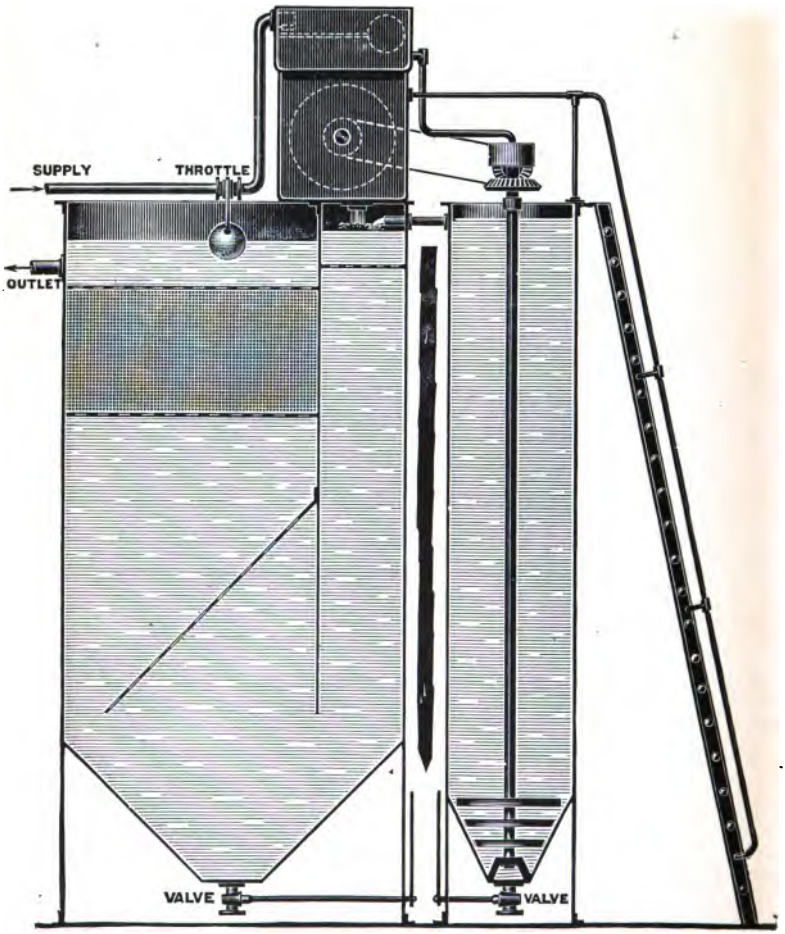

FIG. 4.

rest of the water passing over a water wheel which drives the shaft and mixing paddles in the lime-water vessel. The lime-water, soda solution and hard water meet at the top of the narrow compartment of the softening tower, the mixture falls and then rises up the wide compartment in which most of the precipitate settles out, and passing through the filtering beds of wood wool the clear soft water issues near the top of the vessel.

The supply of water is automatically governed by a throttle valve in the supply pipe, which allows water to pass exactly in proportion to the calls upon it, as shown by the fluctuations of level in the water above the filter bed; the supply of lime-water and soda being governed by the head of water in the inlet tank, the proportions remain always constant, and when the supply of hard water ceases or slackens, the supply of reagents ceases or slackens accordingly, without any manipulation of valves or other gear.

Fig. 5 shows an apparatus with hand-mixed reagents. The proportions of hard water and reagent are kept constant at all speeds by an automatic device consisting of a water inlet tank fitted with a siphon, which discharges the tank, when full, into a second tank fitted with a siphon outlet. The requisite amount of reagent runs into the second tank when empty, checked at the correct height by a float check valve. The water discharged from the first siphon tank washes out all the reagent through the second siphon, leaving the second tank

empty; the next dose of reagent runs in, and awaits the next flush from the inlet tank.

The treated water, after passing through the softening and depositing tank, passes through a sand filter, the latter being quickly cleaned by a rapid flow of water in a reverse direction.

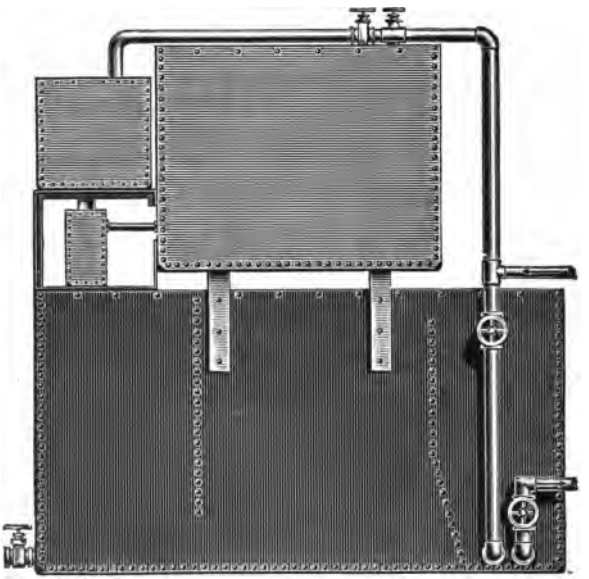

FIG. 5.

Assisted settlement is requisite when the suspended matters are too light to settle freely, as when the water contains vegetable matters either alone or with substances which would settle well if alone, but are retarded by the vegetable matter. In such cases the soften-

ing process is of great assistance, as the chalk formed sticks to and drags down much of the suspended matter. In some cases no other assistance is needed, provided that a proper clarifying vessel is employed. But very frequently vegetable matter is not merely suspended, but is so very finely divided as to be actually or practically dissolved. Many stream waters are quite bright and clear to the eye, but actually contain a large amount of organic matter. In such cases the aggregation of the fine chalk particles into larger and quickly settling crystals is so retarded as to render clarification imperfect, or it may even be altogether prevented. The resulting water may be sufficiently free from mineral matter to be perfectly good for feeding boilers, but it will be very turbid to the eye, and to clear it some more weighty and coherent precipitate must be added which will drag all other matters down with it. For this purpose alumina is very successful, and has the advantage of being cheap. It is obtained as a precipitate in the water by neutralising sulphate of alumina by means of a suitable alkali, generally soda. Occasionally, if hardness is of no consequence, the carbonate of lime contained in the water itself is utilised as the alkali, being changed into sulphate of lime, but the results are not so satisfactory, so rapid, or so complete as when soda is used. For clarifying waste waters the alkali used is quicklime, which is very cheap.

Either reservoirs or settling towers must be employed. The rapidity of the clarification will vary

with the weight of alumina precipitated. In ordinary cases it will be sufficient to use one pound of sulphate of alumina per thousand gallons, with half a pound of caustic soda to neutralise it, and clarification will be complete in about two hours. If the quantities be doubled, the rapidity will be very much increased. Care must be taken that the alkali shall be slightly in excess, otherwise the clarified water will be acid, and dangerous to boilers.

Filtration is the oldest artificial method of clarifying water, and removes the suspended impurities more completely than any other. If filters were self-cleaning, had no wearing parts and were of moderate dimensions, it would be difficult and even unnecessary for other systems to compete with them. But a straining filter which will take out precipitated chalk and requires no cleaning has yet to be invented, and we are therefore limited to filters which can be cleaned with more or less labour. There are also large numbers of filters which *cannot* be cleaned; they are only used for filtering drinking water in houses. Now if any filter *must* be kept clean to be of any practical use, it is one used for drinking water, and yet that is the only one which cannot be cleaned. Such filters, therefore, frequently do more harm than good after they have been in use for a month.

Filters are of many kinds, but may be classed under a few heads. These are—sand filters, block filters, and cloth filters. The highest temporary mechanical effici-

ency is to be obtained from those in which the filtering medium consists of blocks either of spongy iron or of carbon, with or without manganese. These are extremely slow in operation, and although when quite new they can safely be used by inexperienced persons, they cannot be used for large quantities even of clean water, and clog up rapidly. A more efficient material of the same mechanical type is kieselguhr, a natural substance composed of the fossil skeletons of minute creatures, and not unlike chalk in appearance, although really composed chiefly of silica. This is more rapid than the iron or carbon blocks, and is said to be more efficient in removing organisms. All the block filters act by straining, the pores of the block being too small to allow solid particles to pass. This is the reason why they are efficient to start with, and also explains why they require frequent renewal, as the tiny pores speedily become choked up.

Loose-grained filters, such as those in which the filtering medium is sand, granulated carbon, granulated magnetic oxide of iron and equivalent substances, act in a different way. The interstices between the grains are too large to allow them to act as strainers and keep back the finest particles. They act, however, in three different ways. If the water be allowed to pass slowly through, some of the larger solid particles are deposited and form a layer at the top, which, when sufficient in quantity, itself becomes a very efficient filtering medium which is mechanically far better than the sand itself.

Some of the particles simply settle on the grains of sand and stay there. Some of them touch the grains on their way through and stick to them. If the matter in the turbid water consists merely of light substances, the top layer of deposit and some of the inner deposit can be removed by washing in a strong reversed current of water. This must be done whenever the deposit has so choked up the filtering medium as to make the rate of filtration too slow, or when the effluent water shows signs of imperfect filtration.

As a general rule, the efficiency of a filter varies inversely with its rapidity of filtration. A rapid filter will stop large particles but not small. Of course, a medium which *can* pass a rapid flow may be converted into a slow filter by artificially checking the speed of flow, but even then it is not so efficient as a medium which will not permit a rapid flow.

Cloth filters do not filter efficiently at any useful rate of speed until a thin layer of deposit has coated them, so as to fill up or reduce the interstices in the web. They possess the advantage of being fairly easily cleaned by washing and brushing, provided the precipitate which they stop is not of a glutinous nature. Used for removing chalk precipitate they work efficiently at a rapid rate, with a very moderate head of water, three or four feet being often quite sufficient. If, however, the water contains an appreciable amount of hydrate of magnesia, the speed is rapidly lessened, as this precipitate is not at all of a crystalline nature, and

soon stops up the cloths. Nor is it so easy to brush off as precipitated chalk, and frequently necessitates the cloths being dipped in weak hydrochloric acid, and being well washed again before use.

Filter presses are the best known and most useful form of cloth filter, and present a very large filtering area in a very small space. They consist of a series of cloths laid against (generally) vertical grooved iron plates, and clamped together with hollow distance pieces between them so as to form a series of water-tight compartments. The water runs under pressure into all the compartments simultaneously, and passes through the cloths, down the grooves, into the outlet pipe. The solids suspended in the water are stopped by the cloths and have to be washed off from time to time. If the suspended matter is very fine, as is the case with freshly precipitated chalk, the cloths do not, when perfectly clean, stop all of it from passing through, as the pores of the cloth are larger than the finest particles of chalk. The cloth gradually becomes slightly clogged by the arrested chalk, which then acts as an efficient strainer and keeps back the whole of the subsequent solid matter, the filtered water being quite clear. The press is unclamped from time to time, and the cloths washed separately. It is frequently convenient to keep two sets of cloths, and use one while the other is being washed.

In the case of softened water, if any considerable portion of the total precipitate is allowed to pass

into the filters, they will need cleaning at least once every eight hours, and if the precipitate includes magnesia, they must be cleaned oftener. The repeated brushings, of course, wear out the cloths, which must be carefully examined and renewed when necessary, as even a small hole will form a short path for the cloudy water, and will allow it to pass through rapidly. Much of this trouble and expense is obviated if the heavy part of the work of clarification is done by means of preliminary settlement in clarifying tanks. These will steadily remove from 90 to 95 per cent. of the precipitate, and leave the water practically pure for ordinary purposes, such as boilers, washing, scouring, etc. In special cases where absolute clearness is required, the clarified water can subsequently be passed through filter cloths, which, having so little to remove, need little washing. As it takes from one to four hours to thoroughly wash a set of filter cloths, the saving in labour is enormous, while the ecomony in wear of cloths is also very great.

Cloths can only be used economically when the liquid to be filtered does not contain soda in any appreciable quantity, as this chemical is destructive to cloth.

Filter presses should be used, if possible, with only the pressure due to the height of water in the softening towers. With greater pressure, as from a force pump, more water can be forced through, but it will not be so clear, nor will the cloths last so long. Speed is in inverse ratio to efficiency and economy.

CHAPTER VII.

HARD AND SOFT WATERS FOR DRINKING AND COOKING.

Hard water is not necessarily inferior to soft water for drinking. Much depends upon the hardening constituents. If they include a considerable quantity of magnesian salts, the water is liable to cause diarrhœa to strangers, and will at any rate have a slight tendency in that direction. Sulphate of magnesia, or Epsom salts, is very extensively used as a purgative medicine, but a natural water would have to be heavily loaded with it to be at all dangerous or inconvenient to constant users, although it is well known that such waters will act vigorously on strangers. A physician has stated that he never met a genuinely healthy person brought up on water containing a large proportion of sulphates. It is difficult either to confirm or to disprove such a statement, as the number of public town supplies containing much sulphates is very limited. Sulphates, in any quantity, cannot be removed by any commercial process which would leave the water unimpaired, and if a drinking water contains a dangerous proportion, the remedy must be found in a different supply.

It is difficult, if not impossible, to determine what

quantity of sulphate of lime would be dangerous. It is well known that brewers of heavy beer actually add a large amount of sulphate of lime to the water with which the beer is to be made. This is done by passing the water through a vat filled with lumps of gypsum, and the water thus hardened must certainly contain from five to ten times as much sulphate of lime as any public supply water in the country. The water is hardened to improve the taste of the beer. Perhaps it does improve the taste of the beer, and it may tend to increase the thirst of those who drink it. This pleases the drinkers and is profitable to the brewers. Certainly, if sulphate of lime is really injurious, the enormous quantity put into beer must be positively dangerous. Yet the doctors do not tell us so, although they do not recommend its addition. They ignore it. They simply say, "Don't take too much beer." They give the same useful advice with regard to water, and meat, and other good things.

Fortunately drinking water seldom contains much sulphate of lime, the principal mineral impurity being carbonate of lime, against which there is no medical complaint, so it may be assumed that such hardness is not seriously objectionable, unless possibly to gouty patients. But even gouty persons seldom indulge in cold water to excess, at any rate openly, and there are several mineral water manufacturers who supply distilled and aerated water at prices which will not prove ruinous to those who cannot drink ordinary water.

Soft water has occasionally been objected to for several reasons. These reasons, however, apply exclusively to water which is *naturally* soft, and it is only by mistake that they are urged against water which, originally hard, has been softened by the lime process. The first objection is that naturally soft water, if it contains those organic acids existing in waters collected from peaty surfaces and moors, dissolves lead in the service pipes, and is thereby rendered dangerous. The addition of a very tiny quantity of carbonate of lime to such water deprives it of its power of dissolving lead, and softened water, which *invariably* contains carbonate of lime, is absolutely safe.

A second objection to natural soft water is that it does not supply the lime required to form the bones of growing children. It is doubtful whether the amount of lime in drinking water is of importance in this instance, seeing that it can never be in any degree comparable with the amount of lime (as phosphate, etc.) contained in bread and porridge. It has been stated that the Scottish Highlanders, who can only get soft water, and who are certainly not deficient in bone, are saved because the deficiency of lime in the water is compensated by the abundance of lime in the porridge, but the inhabitants of large towns such as Glasgow, Manchester or Bradford, do not eat much porridge, even as children, and yet they are not noticeably afflicted with rickets or weak bones.

A much stronger objection to some natural soft waters is that they contain vegetable substances in

solution. These are far more dangerous than any mineral impurities, but fortunately they can be removed by efficient slow filtration through ordinary sand beds. And it must here be claimed, on behalf of softened water, that if the hard water contains organic impurities, the softening process removes a very large proportion of them.

It is now time to consider the wholesomeness of softened water. The consensus of medical opinion is emphatic in its favour. In itself it combines all the good qualities of water without any added disadvantages. It cannot dissolve lead; the softening process actually removes organic matters as well as mineral; it removes the excess of chalk objected to by some, while retaining enough to satisfy those who consider a little to be advantageous; the taste is not altered, nor the temperature; the oxygen in the water is not removed. Dr. Frankland states: "Water, the hardness of which is wholely or largely of the temporary kind, may be easily, cheaply and efficiently softened on the large scale by the proper use of lime; the wholesomeness and palatability of such water are sometimes increased and never diminished by the process. The lime method of softening may be applied with ease and great economy to the whole supply of even the largest towns, provided the hardness of the water be wholly or chiefly of the temporary kind."

Professor Wanklyn says: "By this process not only is the water softened, but a very large proportion

of the organic matter contained in it is removed, and, if the water be coloured, the colouring matter is also entirely or in very great part removed. The process presents so many advantages, and is so simple, that we are surprised not to see it in general use, and naturally expect to find on investigation that it has some great drawback. This, however, does not appear to be the case." He gives the following examples, from actual experiments, to show to what extent organic matter is removed by this process :—

		Parts per Million. Albuminoid Ammonia.
1	Before Clark's process	·050
	After „	·020
2	Before „	·220
	After „	·080
3	Before „	·220
	After „	·070
4	Before „	·120
	After „	·060

Albuminoid ammonia is regarded as an index to the amount of albumen or nitrogenous organic matter present in water, and constitutes a most valuable test for water pollution.

The lime process may frequently be utilised to render water pleasant and safe which might otherwise be undrinkable, as, in combination with a suitable filter, it enables large quantities of water to be cleared of all suspended and much of the dissolved impurities, especially when these are simply such as are to be looked for in streams or wells not polluted by sewage.

Where sewage pollution exists, the water cannot safely be used at all for drinking, even after thorough filtration. The sewage contamination can undoubtedly be much diminished by softening and filtration, but absolute removal or destruction of the dangerous organic matter can only be effected, on any large scale, by oxidation; this is a slow process, and no rapid process can entirely replace it.

Purification of drinking water by the "alum process" has been resorted to for hundreds of years in many parts of the world, the method adopted being to add a known weight of powdered or dissolved alum to a known quantity of water, stir it up, and allow it at least twelve hours to settle. The water so purified is almost always river water, and the results are generally fairly satisfactory as regards clearness, although pollution by sewage is not completely removed. This is really the same as the employment of sulphate of alumina already referred to, and we may repeat here that the method can only be employed when the water contains carbonates, which are converted into sulphates during the reaction which takes place. This may be open to objection from a dietetic point of view, and the alum process should not have the preference, if a better method is available. Care must also be taken not to add more alum than can be decomposed by the carbonates in the water, otherwise it will not all be precipitated, but some will remain in solution.

The machines and apparatus already described

in Chapter VI. can be used alone for the treatment of water for drinking and cooking, provided they are made of sufficient size to completely remove the precipitated chalk. But as the last portion of the precipitate is extremely fine, and settles with great difficulty, it is best for this special purpose to keep the apparatus comparatively small, and to supplement it with a filter.

CHAPTER VIII.

TESTING HARD WATERS.

When samples of water are taken for analysis, care must be taken that there shall be nothing in the containing vessels which can alter the nature or quantity of the different substances dissolved or suspended in the water. Therefore it is in all cases best to put the water into large glass jars or bottles (those called Winchester quarts are very convenient) which have previously been well rinsed out, the final rinse being given with some of the water of which a sample is being taken. If glass jars are not obtainable or cannot conveniently be forwarded, then stoneware jars should be used, such as are used by brewers for sending out family ales; these must be very carefully cleaned, as a little drain of ale or stout would completely alter the nature of the water.

Stoneware jars are not so good as glass, because the earths of which they are composed are seldom completely vitrified inside, and some of the earthy matter is dissolved out by the water. We have found a water of 20 degrees of hardness to harden up to 45 degrees on being left in a small *new* stoneware jar.

This defect shows itself chiefly with new jars. Old jars have generally already lost the soluble part of their inner surfaces, and may then be used with practical safety after being thoroughly well washed out.

Tinned bottles or cans should never be used if glass or earthenware be available, as the carbonic acid present in the water attacks the iron of the can. If the circumstances are such that only a tin bottle can be sent, it *must* first be washed out with hot water. New cans always contain a very perceptible quantity of chloride of zinc, which has been used as a flux to facilitate soldering up the edges. Old cans have frequently (in fact generally) contained oil, which can only be removed by the free use of hot water with plenty of soda dissolved in it. Such cans should never be used except as a last resort. Round cans are not so bad as square ones; the latter are almost always damaged in transit.

If a sample of stream or other dirty water is likely to be some days before it is tested for mineral impurities (as when sending samples from abroad, or just before general holiday times), it is best to filter it through clean blotting paper before sending, or through a double fold of linen. This is because organic matter, in the presence of sulphate of lime, sulphate of magnesia or sulphate of soda, has a tendency to decompose and change these sulphates to carbonates, while sulphuretted hydrogen is liberated. Such a change, of course, renders the sample of water perfectly useless.

In fact, no sample which on being opened is found to smell appreciably of sulphuretted hydrogen can be relied upon for analytical purposes.

In every case it is important that the analyst should be informed of the source from which the water comes—i.e. whether it is from the town's supply, from a well or spring, or from a canal, or river, or small stream. If the source is known to be liable to contamination from sewage, from pollution by factories, soap-works or dye-works, or to be liable to changes of any sort, as is frequently the case with pit waters, as much information as possible should be given to the analyst. It commonly happens that samples of water are received without any accompanying information, with an inquiry as to what can be done with the water, under guarantee. In such cases a guarantee can only be given in respect of water which is practically identical with the sample tested, and which may, after all, not be a fairly representative one.

Many well waters are perfectly clear and bright when pumped, but after a time become cloudy from precipitated iron, or from chalk, the former occasionally being in such quantities as to turn the water nearly black. The ultimate colour is red, and a lot of iron rust is deposited. Now this peculiarity of the water should be made known to the analyst, as, although he may suspect it, the presence of an iron oxide deposit is not conclusive information, and the treatment of the water may require modifying in accordance with the

different nature of the water when first pumped. It is best always to run water into a softener in the same state all day and every day. For instance, we have known pit or well waters pumped first into a small reservoir at intervals, and thence run continuously into a softening apparatus. Now these waters, when first pumped, contained a good deal of bicarbonate of iron and also of free carbonic acid. While standing in the reservoir much of the carbonic acid escaped, and some of the iron was precipitated. The consequence was that while the water was pretty fresh it required about 25 per cent. of lime-water added to soften it; at the end of a few hours it needed only 20 per cent., or even less. Such variations require more careful watching than it is possible to give, and therefore it is not surprising that the results were irregular, the softened water showing at one time say 3 degrees of hardness, and at another 10 degrees, all within a few hours, and with the same proportions of saturated lime-water.

Waters may be tested, partially or completely, in several ways. The usual method, given in the text books, we do not intend to describe. It is by far the slowest, and involves much expenditure of time and care in evaporating the water under special conditions, with and without the addition of certain chemicals, in separating the solid residues, both soluble and insoluble, and then in weighing them accurately in delicate balances after thorough desiccation, ignition and cooling. The method is in itself the most accurate

which can be devised, and must be resorted to if a complete and minute mineral analysis be required, but it requires a high degree of special knowledge, experience and manipulative ability, without which the results obtained are worthless. It is adopted by expert chemists when a complete analysis of mineral impurities is required, and such an analysis should be made of every water likely to be largely used. Accurately, however, as the method may be made, it is always difficult, and two expert chemists will seldom return exactly the same analysis of the same water. This is especially the case with the salts of magnesia. In unsoftened water for boilers the presence of chloride of magnesium is important; yet this is of all the impurities the last and most difficult to be determined.

Now when water is in actual use and undergoing treatment, it should be tested, at least partially, not once a year or once a month, but every week or every day, and perhaps oftener. The usual slow and complicated method of analysis is not then practicable, and a few special tests have been devised which, without evaporation, weighing, or specially skilled manipulation, will show in a few minutes the hardness, alkalinity or acidity of the water, and the exact strength of the reagents or solutions which are being used. The method, which is called the volumetric method, as distinguished from the ordinary or weighing method, consists, shortly, in adding exactly measured volumes of reagents of known strength to exactly measured volumes

of water or solutions of unknown strength, an indication being given, either by change of colour or by other means, when the exact quantity required of the testing reagent has been added. The change of colour is obtained by addition in minute quantity of certain dyes, which change colour according to the acidity or alkalinity of the water. Such dyes are litmus, turmeric, cochineal, phenolphthalein, methyl-orange and many others, and they are therefore called *indicators*. In treating hard water, two principal tests are used—viz., with soap and with acid.

THE SOAP TEST.

It has already been stated that lime and magnesian salts in solution destroy or neutralise soap in quantity roughly proportionate to that of the salts. That is, they combine with the fats (called fatty acids) contained in soluble soap, and form an insoluble earthy soap which cannot (being insoluble) make a real lather, although it may form a solid curd or scum which has no detergent or washing power. If the mixture be shaken up, no lasting lather or foam will form unless the quantity of soluble soap added is in excess of what the lime and magnesia can destroy. It is upon this fact that the soap test is based, the inventor being the same Dr. Clark who invented the process of softening by lime.

The soap test is one which, without possessing absolute accuracy, is the most generally useful method

devised for testing the hardness of water. It is most useful because it is easy, quick and generally reliable, even in unskilled hands, and its indications must always be treated with respect. Its failing is that while it shows the total hardness of the water, it does not discriminate between lime and magnesia to any useful extent. The method of testing will now be described. The description is pretty long, but the test takes less than ten minutes.

The quantity of water to be tested is 70 cubic centimetres. The reasons for fixing on this quantity are—firstly, that it is a convenient one to handle, and requires only a small quantity of reagent; secondly, this quantity (which is $\frac{1}{64 \cdot 9}$ of a gallon) is such that it contains just as many milligrams as a gallon contains grains. It may therefore be regarded as a miniature gallon, with milligrams representing grains. We believe the adoption of this volume, and also the method of using Clark's test which we recommend, is due to Professor Wanklyn. Dr. Clark's methods were much less simple. He aimed at absolute accuracy, of which the test is not capable, and made tables of strengths and hardness which, although perhaps exact enough with certain waters, are by no means generally applicable, and his method is now abandoned. When "degrees Clark" are mentioned, we do not now mean degrees according to Dr. Clark's tables; we really mean "degrees Wanklyn." It will be seen further on that each such degree corresponds to one

grain (per gallon) of carbonate of lime, or to lime or magnesian salts of equivalent soap-destroying power. Another standard is sometimes used, in which 100 c.c. of water are tested; the resultant degrees, instead of corresponding each to one grain per gallon of carbonate of lime, correspond each to one part (or grain) per 100,000. As a gallon of water contains only 70,000 grains, it will be evident that this latter test will give figures exceeding Wanklyn's in the proportion of 10 to 7. This volume of water (100 c.c.) for testing was invariably used by Dr. Frankland, and the corresponding degrees of hardness are frequently called "degrees Frankland." We shall not refer to them again, but only to "degrees Wanklyn," now commonly called for convenience "degrees Clark."

The 70 c.c. of water is placed in a clean glass bottle large enough to hold two or three times as much. A clear solution of soap, of standard strength, is gradually added from a graduated tube (called a burette), marked in cubic centimetres, and the mixture is briskly shaken. A slight lather may form at first, but the bubbles will quickly break up and disappear, if the proportion of earthy salts is in excess of the soap added. More soap is added, shaking the bottle after each addition, until the lather formed is sufficiently permanent not to disappear on standing for four or five minutes The number of cubic centimetres of soap solution added, less one, indicates the hardness of the water in degrees, one degree being equivalent to one grain of carbonate

of lime per gallon. One degree is deducted because even fresh distilled water requires some slight quantity of soap to make it lather, and the quantity needed is almost exactly that which is neutralised by one degree of carbonate of lime. Burettes made specially for use with the soap test are therefore marked with one degree (or cubic centimetre) above the O.

Standard soap solution is of such strength that one cubic centimetre contains sufficient soap to exactly neutralise one milligram of dissolved carbonate of lime.

It is obviously important to ascertain the point at which a satisfactory lather is formed. The method usually recommended is, after shaking the soap and water briskly for a second or two, to lay the bottle on its side; if the lather still remains after five minutes, although perhaps diminished in volume, it is satisfactory. A quicker method is, after shaking the bottle, to uncork it after ten seconds and listen to the breaking of the bubbles. If much more soap is needed, the bubbles will break freely with a hissing sound. As more soap is added, the sound becomes muffled, or, so to speak, fat, while a good lather gives little or no sound at all. A few seconds should elapse between shaking the bottle and listening to the sound, as with some waters a few large bubbles will break at first, and then there will be silence, while with others there will at first be no sound, but the bubbles will shortly begin to break and hiss. This latter is especially the case when the water contains either magnesia or hydrate of lime.

There is a difference between lime and magnesia under the soap test. The reaction between the lime and the soap seems to take place almost instantly, while that when both lime and magnesia are present takes time. A water of 10 degrees of hardness, due 5 to lime and 5 to magnesia, will lather profusely on running in 6 or 7 degrees of soap, but after waiting two or three minutes the lather will break up, and cannot be produced again until the remaining quantity of soap has been added. This peculiarity may be turned to useful account by indicating the presence of magnesia, while a rough idea of its proportion may even be gained. The presence of magnesia in any quantity renders all tests more difficult and less reliable, and they must therefore be made with greater care.

Another difference between lime and magnesia is in the amount of soap destroyed by quantities chemically equivalent. Professor Wanklyn, whose experience on the subject is very extensive, states that magnesia destroys more soap than lime does, in the proportion of 75 to 42. Campbell states that up to 6 grains per gallon, magnesia has an effect equivalent to that of lime, but not over that quantity. Our own experience tends to confirm Wanklyn's observations, but in a very large number of cases we have found quite contrary results. We have found waters in which magnesian salts, although present in very noticeable quantity, caused little or no destruction of soap; in such cases there has always been at least a trace of carbonate of

soda. In many waters the magnesian salts have not destroyed more than one-third the calculated quantity of soap, when tested undiluted, but when tested diluted with distilled water, the effect of the magnesia has acquired full value.

The observer should not be satisfied with a single test of an unknown water; several should be made and they will sometimes be found to vary somewhat. It is well to try the water first undiluted, and then diluted with an equal volume of freshly distilled water. If the water contains wholly or almost wholly lime salts, the two tests will almost invariably correspond, but if there are several grains of magnesian salts, the diluted water will show more hardness (allowing for dilution) than the undiluted water. The water should be as fresh as possible, or tested in the same condition in which it would be used. Water containing much carbonate of lime in solution is apt to lose carbonic acid on standing, and deposit a portion of the carbonate of lime, thus becoming softer. When taking samples for testing, the bottles or jars should be well washed out first, and then rinsed with the same water which is to be tested. Old wine bottles are apt to contain a deposit, while old beer bottles are usually distinctly acid.

Water containing vegetable matter has a natural tendency to froth, which slightly interferes with the soap test. The presence of free carbonic acid in any quantity appears to increase the hardness of the water

—that is, its power of destroying soap. Fresh distilled water, which will lather freely with 1 c.c. of soap solution, will no longer do so after blowing into the testing bottle and shaking. If distilled water is allowed to stand, it absorbs carbonic acid from the atmosphere, so much so, indeed, that if used in that condition it may seriously impede any tests and cause inaccurate results. Distilled water used should therefore either be fresh or be re-boiled before use.

Mohr's burette is generally used for measuring out the standard soap solution. It consists (see Fig. 6) of a glass marked with divisions of one cubic centimetre each, and, if desired, with subdivisions. This is supported vertically. Over the bottom end, which is pointed, is slipped a short rubber tube, in the lower end of which is a short piece of glass tubing drawn to a point, leaving only a small opening. The rubber tube is closed by the pressure of a spring clip. The upper end of the burette may be enlarged for convenience in filling. The soap solution is poured in at the top, and after filling, the rubber tube should be squeezed two or three times to remove the air just above the clip, while a little of the solution should be quickly run out by pressing the ends of the clip, before making any tests, so as to fill the glass jet and lower part of the rubber tube with liquid. The burette is then refilled to the top mark. Owing to capillary attraction, the liquid in the burette does not present a level surface, but is concave. The lower curved line of

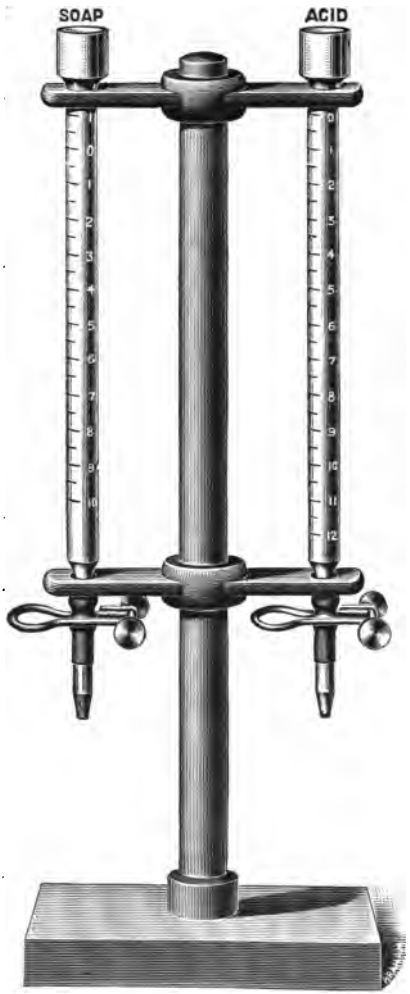

FIG. 6.

the concave is sharper and better defined than the top, and should always be made to coincide with the graduation mark when filling the burette, and also to mark the reading at the end of the test. The burette can be read more easily if a very narrow strip of white paper, with a straight red or black line down the middle, be pasted lengthways behind the tube. The effect of the transparent solution is to magnify the strip and line, and the level of the liquid is marked by a sudden change in the width of the line.

To obtain the most reliable results, not more than one cubic centimetre of solution should be added to the water at once; the bottle should then be shaken, and if no lather forms, another c.c. is added, and so on; but as soon as a temporary lather forms, the quantity of each addition should be diminished.

Chemists have sometimes urged that the indications given by the soap test cannot be relied upon, because different degrees of hardness are given by different experimenters with identical waters. This arises from two principal causes. It is found that a soap solution containing an over large proportion of water does not keep its strength, especially in cold weather, part of the dissolved soap being precipitated; the original strength is restored by warming before a fire and shaking briskly. A much larger proportion of alcohol will prevent this precipitation, but materially affects the accuracy of the higher (or harder) readings, say above 10 degrees. This is due to the fact that the presence of alcohol tends to prevent lathering, so much so that a solution of soap containing three parts of water and one part of spirit will not make a permanent lather at all, unless diluted. This leads to the second cause of divergent readings. When the hardness of the water is greater than 15 degrees, the quantity of alcohol in the soap solution added is sufficient to interfere with the lather; in such cases the hard water should be diluted with distilled water, using 35 c.c. of hard and 35 c.c. of distilled water; the hardness degree of the

mixture must be doubled to obtain the true degree of the water. If the water is very hard indeed, smaller proportions of it may be used, with sufficient distilled water to make up 70 c.c., the readings being multiplied accordingly. It is evident that if various experimenters use solutions with different proportions of alcohol, they will obtain readings which will, or may, vary more or less. Or the solutions may have been standardised at different degrees—one at 6 degrees, another at 10, another at 16 degrees. Now an alcoholic solution of soap is only perfectly accurate at the degree at which it was standardised. It may be accurate at 6, and 10 per cent. wrong at 16, or *vice versâ*. Therefore a soap solution is best standardised at the degree at which it will be generally used. We prefer to standardise at 10 degrees, and to make the solution by dissolving Castile soap in a mixture of two volumes of ordinary methylated spirit and one volume of water. Soap solution so made is good alike in cold weather and in hot, although it would be, when fresh, more accurate over a long range if it contained a larger proportion of water.

The propriety of diluting very hard water for testing has been questioned by some chemists, who say that the hardness found is only that of the diluted water, and that the plain water itself would actually destroy a very different proportion of soap. The objection is plausible but the statement is not susceptible of proof. The aim in diluting the water is two-fold—

first, to minimise the interference of the scum or insoluble curd formed by the decomposition of the soap; secondly, to employ less alcohol; and the smaller the proportion of alcohol used, the nearer will the conditions of the test approximate to those of actual technical practice, in which, of course, no alcohol is used at all.

Another point on which much misapprehension exists. The hardness of water *does not mean* so many grains or so much weight of lime salts and magnesian salts in solution; it means so much soap destroyed. It is idle to say (as some experimenters do say): "This water destroys (say) 12 c.c. of standard soap solution, and according to our (private) tables that means 16 degrees." It means nothing of the kind. An analysis may show the *chemical* equivalent to 16 grains per gallon of carbonate of lime, but it will not be the soap-destroying equivalent. That will be only 12. It is useless and only misleading to try to make the soap test corroborate exactly the analytical result. The thing is absolutely impossible. Salts of magnesia appear under certain (or rather uncertain) conditions to have little or no effect upon the soap test, while under others they have more than their calculated effect. The following are both analytical and hardness tests of water from the same deep well at three different periods, essentials only being quoted, each test being verified by independent experimenters.

	No. 1.	No. 2.	No. 3.
Carbonate of lime	12·50	10·80	14·40 grs. per gall.
Carbonate of magnesia ..	5·38	4·91	4·01 „ „
Carbonate of soda	0·75	1·08	0·44 „ „
Hardness, calculated ..	19·0	16·7	19·3 degrees.
„ by soap test ..	17·0	13·5	18·8 „
Alkalinity tested, equivalent to	19·5	19·0	19·5 grs. of $CaCO_3$ per gall.

Nothing can possibly make all these different tests agree. It will, however, be noticed that the quantity of carbonate of soda present is largest, when the hardness readings are lowest. The amount of carbonate of soda is quite inadequate to affect the hardness to the extent shown, and it may possibly be that a portion of the carbonate of magnesia and the carbonate of soda form some definite compound which has but little or no power of attacking and decomposing soap.

Some waters produce at first, not a true lather, but a curdy scum containing imprisoned air, which lasts a long time, is quite silent, and may very easily be mistaken for a genuine lather. If, however, the body of water below the froth is nearly clear and transparent, it may be considered certain that the froth is only a scum, for with hard water the real lather does not form until the water becomes permanently milky and opaque. We have occasionally found that this scum, which is generally due to carbonates, may be avoided by carefully neutralising the water with the proper quantity of dilute acid before testing (see acid test), using methyl-orange as indicator and then boiling; this addition of acid does not, in these particular cases, appear to increase the

hardness of the water, although in most cases it does so very materially.

The presence of precipitated or solid chalk in ordinary quantities has no appreciable influence on soap, and the soap test can therefore be applied while the water is quite milky with precipitate, without affecting the accuracy of the test. Such is not the case with the acid test. We must remark, however, that for a few minutes after forming, the precipitate of chalk, and even more particularly of magnesia, *does* affect soap; this is only while the precipitate is in a woolly flocculent condition; after some minutes it becomes granular and crystalline, and in that state it is neutral to soap.

THE ACID TEST.

The temporary hardness of water (due to carbonates) may generally be easily and reliably ascertained by testing its alkalinity with acid. The carbonates of lime and magnesia are weak alkalies, and their quantity can be tested by neutralising with a standard weak solution of acid, using a drop of methyl-orange as indicator. Methyl-orange is of a pale lemon-yellow in alkaline liquids, even in the presence of carbonic acid, by which it is not affected, and it retains its yellow colour upon addition of sulphuric acid until the point is reached when all the carbonates have been changed into sulphates; the colour then changes to a weak

orange, and the slightest excess of acid changes it to pink or red, faint or pronounced as the excess of acid is slight or otherwise. If the solution of acid be of the strength known to chemists as $\frac{N}{50}$, or one-fiftieth of the normal strength (which in its turn is only about one-thirtieth the strength of concentrated sulphuric acid), one cubic centimetre will neutralise one milligram of carbonate of lime, or (if 70 c.c. of the water be tested) at the rate of one grain per gallon. The hardness due to carbonates of lime and magnesia is indicated by the number of cubic centimetres of acid required to neutralise 70 c.c. of the water. The water may possibly contain carbonate of soda; in this case the alkalinity of the water will *exceed* its hardness, and *all* its hardness will probably be due to carbonates, for in a natural water carbonate of soda is seldom accompanied by sulphate of lime or sulphate of magnesia.

But if the acid test and the soap test, applied to hard water, show the alkalinity to be in excess of the hardness, this must by no means be accepted as showing either that there is no permanent hardness in the water or that the water contains carbonate of soda. In many waters the hardness indicated by soap is less—sometimes much less—than corresponds to the lime and magnesian salts present.

The most reliable way of ascertaining this point is to soften a sample of the water *with lime only*, allow it to stand for two hours or more, then filter and test with

acid and soap. The softening process appears to remove most sources of interference, and the results of the tests are reliable. The same result is frequently arrived at by boiling the hard water for half an hour, filtering and testing.

The following actual examples of well water will illustrate the point:—

Sample.	Test with.	Untreated.	Boiled.	Softened.
		degrees.	degrees.	degrees.
1	Soap	17	7	8
	Acid	16	3	3½
2	Soap	15½	..	5
	Acid	16	..	2½
3	Soap	30	12	18
	Acid	40	12	21
4	Soap	19	10½	11
	Acid	19	4½	3
5	Soap	28	15	21
	Acid	33	5	14
6	Soap	21	10	14
	Acid	27	6	12

No. 3 contained carbonate of soda, but would not soften satisfactorily without boiling. The other waters contained no carbonate of soda, but No. 5 contained much sulphate of magnesia, which is not suitable for softening with lime.

Some of the above are unusual cases, but they indicate to what extent the rapid volumetric method

falls short of the more tedious methods of the text books. Yet in most cases it will give all the information needed for softening and other treatment with quite satisfactory accuracy.

A caution must here be given with regard to filtering softened water or weak alkaline solutions before testing. Filter paper absorbs carbonic acid to a very appreciable extent, and if softened water be poured into a new dry filter paper it will take up this carbonic acid, and will not show the full degree with phenolphthalein as indicator.

The strength of lime-water and of soda solutions may be tested in the same way, using acid of the same strength.

When testing lime-water, either methyl-orange or phenolphthalein may be used as indicator. Phenolphthalein is preferable in this particular case. It has a purple-pink colour in the presence of the hydrates of lime, magnesia and soda, and also in the presence of the mono-carbonates of lime, magnesia and soda, but is colourless to the bicarbonates of lime and magnesia, it being deprived of colour by all acids, including carbonic acid either free or combined as bicarbonate. The full alkaline strength of a solution is indicated when using methyl-orange, but with phenolphthalein only such alkalinity as is not masked by carbonic acid. A natural water containing bicarbonates does not test alkaline to phenolphthalein, but on boiling, the pink colour will appear as the carbonic acid is driven off.

5 c.c. of saturated lime-water should be neutralised by 11½ c.c. of $\frac{N}{50}$ acid, or in very cold weather by a trifle more. If it takes less it is not saturated (unless warm); if it takes perceptibly more, it contains solid lime (or in some few cases soda). When soda is mixed with the lime-water, the strength of lime cannot be ascertained by the acid test, and the soap-test must be used; take about 70 c.c. of distilled water, and add 5 c.c. of the mixed lime-water: the mixture should indicate about 9 degrees of hardness, making a lather which, although extremely abundant, will *not* last five minutes.

Dilute solutions of caustic soda may be tested with both phenolphthalein and methyl-orange; phenolphthalein is added first, and then acid, until the colour disappears; methyl-orange is then added, and the neutralisation completed. The difference, doubled, indicates the carbonate of soda always present, and should be very small. Carbonate of soda is tested in the same way, but there will be a very wide difference between the two readings; if washing soda, soda ash, or pure alkali be used, the test with methyl-orange will require twice as much acid as with phenolphthalein; if the concentrated crystals (sesqui-carbonate) be used, it will require three times as much.

The dilute caustic soda solution will vary in strength according to the weight of reagent required per thousand gallons, and the rate at which the solution is allowed to flow.

TEST SOLUTIONS.

These can only be made accurately by checking them with other exact standard solutions, but if the latter are not available, solutions can be made by the following easy methods with sufficient accuracy for ordinary use, when testing water-softening operations in actual practice. There must, of course, be some one substance or solution which will be, automatically, of practically constant strength. Such is found in saturated lime-water. If this be made always in the same manner, at the same temperature, and with freshly slaked lime, it will have the same strength within 2 or 3 per cent. With this saturated lime-water all the other solutions are checked, and we therefore give it first.

Saturated Lime-Water.—Slake about two ounces of quicklime, let it cool, then put it into a large bottle with about a quart of cold water (temperature 60° F. or near it), and shake it up well half-a-dozen times at a few minutes' interval; allow the lime to settle, and filter the liquid through clean blotting paper. When freshly made and filtered, 5 c.c. will be neutralised by $11\frac{1}{2}$ c.c. of $\frac{N}{50}$ sulphuric acid, but on standing a few days it may weaken a little, and 5 c.c. will be neutralised by 11 c.c. of acid.

$\frac{N}{50}$ Sulphuric Acid.—Dilute ordinary sulphuric

acid with water (about 1 of strong acid to 1500 of water) until 11½ c.c. of the dilute acid just neutralise 5 c.c. of saturated filtered lime-water, freshly made, using phenolphthalein as the indicator. This solution will keep any length of time in glass bottles, but will not keep a week in a stoneware jar.

Soap Solution.—Put about half an ounce of Castile or mottled soap, shredded fine, into a mixture of methylated spirit and water (2 pints of spirit to 1 pint of water), and let it stand for a few hours, shaking it at intervals. The mixture should *not* be warmed. Then filter it through blotting paper, and test its strength by means of water of known hardness, gradually diluting it (with more of the mixture of spirit and water) until its strength is just right.

Water of Known Hardness.—Take 5 c.c. of saturated lime-water, neutralise it with $\frac{N}{50}$ acid, and make up to 70 c.c. with freshly distilled water. The hardness of this artificial water should be as many degrees as the lime-water needed cubic centimetres of acid to neutralise it.

Phenolphthalein Indicator.—Dissolve 10 to 20 grains in a pint of methylated spirit (or in that proportion). One drop of the solution is enough to show the purple-pink colour in a test, but there is no harm in adding more; the colour becomes deeper, but does not take more acid to remove.

Methyl-Orange Indicator.—Dissolve 7 grains in

a pint of distilled water. Add one drop (only) to every 70 c.c. of water or solution to be tested. The change from lemon yellow to orange or pink is only visible clearly in daylight; if used by gaslight, add an extra drop of the indicator, and hold the vessel in front of a sheet of white paper,

Turmeric and litmus are best used in the form of saturated papers, which are sold in little book packets. They are convenient to carry in the pocket, but are not so sensitive or so easy to use as phenolphthalein.

USEFUL DATA ABOUT WATER.

1 pint of water weighs 20 oz. avoirdupois.

1 gallon of water weighs 10 lb., or 4·543 kilograms.

1 gallon of water equals 4·543 litres, or 4543 cubic centimetres.

1 cubic foot of water contains 6·2355 gallons, weighs 62·355 lb.

1 cubic foot of water contains 28·3 litres, weighs 28·3 kilograms.

1 indicated horse power requires, in the best condensing engines, about 1¾ gallon of water evaporated per hour.

1 indicated horse-power requires, in large non-condensing engines, about 2½ gallons of water evaporated per hour.

1 indicated horse-power requires in small non-

condensing engines from 3 to 10 gallons of water evaporated per hour.

1 pound of coal will evaporate from 7 to 10 lb. of water from 60° F.

1 ton of coal will evaporate from 1600 to 2200 gallons of water from 60° F.

1000 gallons of water cost from 4*d.* to 1*s.* 6*d.* to buy.

Ditto cost from 7*s.* to 12*s.* to evaporate.

Ditto cost from ¼*d.* to 3*d.* to soften.

Ditto of 12° hardness waste 20 lb. of best soap.

Ditto of 16° hardness deposit 2¼ lb. in the boiler.

1 cubic foot of water makes 283 cubic feet of steam at 80 lb. pressure.

Ditto makes 1642 cubic feet of steam at atmospheric pressure.

1 gallon of water requires 454 calories to raise it from 32° F. to 212° F.

1 gallon of water at 212° F. requires 2436 calories to convert it into steam at atmospheric pressure.

1 pound of water at 32° F. will condense 0·1864 lb. of steam at 212° F.

1 pound of steam at 212° F. will raise 5⅓ lb. of water from 32° F. to 212° F., if no heat be lost.

1 pound of steam requires 20 lb. of water of 60° F. to condense it, using surface condensers.

A surface condenser requires 3 square feet of surface for every horse-power indicated.

FLOW OF WATER THROUGH STRAIGHT PIPES.

FLOWING FULL, IN GALLONS PER MINUTE.

Diameter in Inches.	Head of Water divided by Length of Pipe.								
	1/100	1/50	1/25	1/10	2/10	3/10	5/10	8/10	1/1
1/16	..	..	..	·024	·036	·046	·06	·077	·086
1/8	..	..	..	·056	·075	·089	·124	·158	·18
3/16	..	..	..	·14	·21	·26	·34	·44	·50
1/4	..	..	..	·31	·44	·52	·72	·92	1·04
3/8	·22	·33	·5	·83	1·2	1·5	2·0	2·6	2·9
1/2	·46	·70	1·0	1·8	2·5	3·1	4·1	5·3	6·0
3/4	1·33	1·98	2·9	4·9	7·1	8·9	11·7	15	16·9
1	2·79	4·15	6·1	10	14·8	18·4	24	31	35
1 1/4	4·96	7·36	10 8	18	26	32	42	54	61
1 1/2	7·93	11·75	17·2	28	41	51	67	86	97
1 3/4	11·7	17·4	25·5	42	61	76	100	128	144
2	16·6	24	36	59	86	106	140	179	202
2 1/2	29	43	63	104	151	188	246	315	354
3	46	69	101	166	240	298	390	500	562
4	98	144	210	344	498	617	808	1033	1162
5	173	254	370	606	876	1085	1419	1815	2040
6	227	404	589	959	1389	1720	2248	2876	3230

If the diameter be doubled, nearly 5·8 times the quantity can be passed.

TEMPERATURE OF STEAM AT VARIOUS PRESSURES.

Pressure. lb.	Degrees F.	Pressure. lb.	Degrees F.
Atmospheric	212	50	297·7
5	227·2	60	307·2
10	239·4	70	315·8
15	249·7	80	323·8
20	258·7	95	334·3
25	266·8	105	340·8
30	273·9	115	346·9
35	280·6	125	352·6
40	286·7	135	358·1
45	292·4	145	363·2

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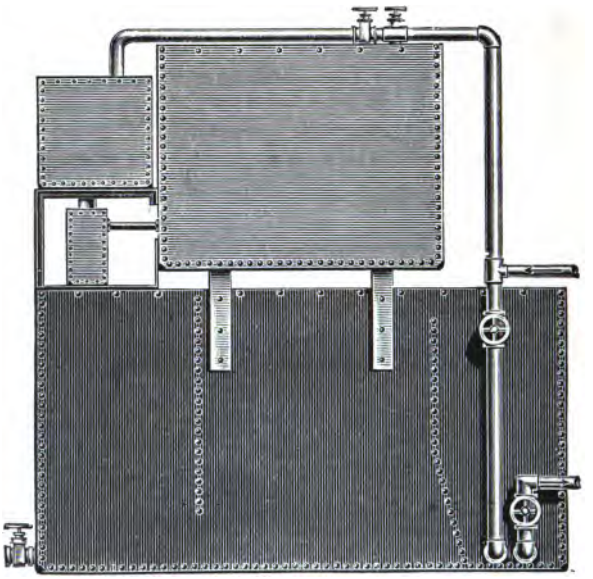

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